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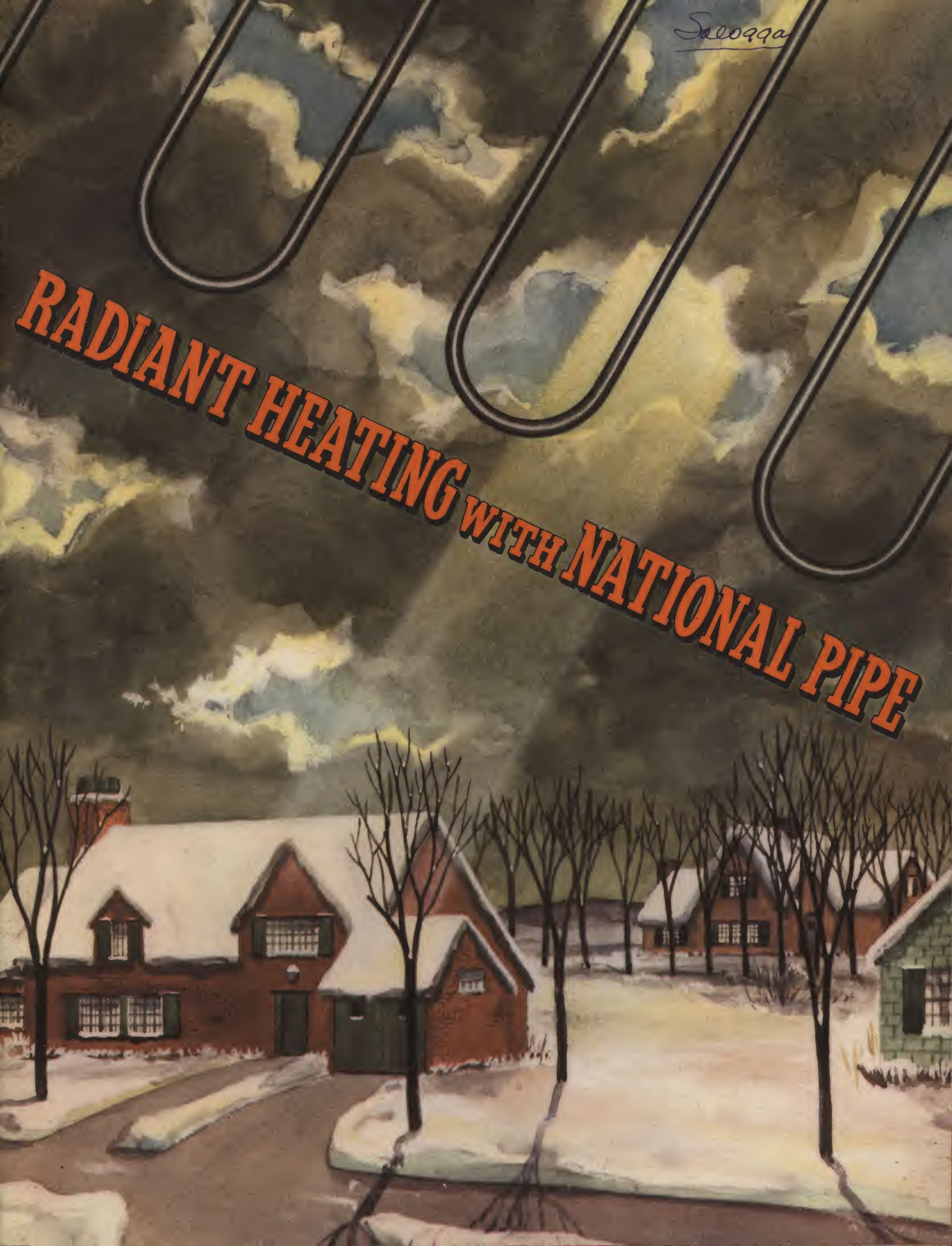
RADIANT HEATING WITH NATIONAL PIPE



RADIANT HEATING

WITH NATIONAL PIPE

BULLETIN Nº 19

NATIONAL TUBE COMPANY
PITTSBURGH, PA.

UNITED STATES STEEL

Radiant Heating

PROBABLY NO INNOVATION in the building industry within recent years has created such broad and enthusiastic interest as has the subject of radiant or panel heating. Certainly it has set in motion a series of technical discussions and popular articles in the business and daily press which have given it near, if not top ranking, in news of the building industry. Architects, engineers, contractors, and prospective home owners alike have shown a keen interest in the possibilities of applying this much publicized method of heating in building plans now in hand or under consideration.

Radiant heating, however, is not a new or an untried idea. For over a decade it was successfully used in Europe before it came into prominence in the United States. Contrary to some popular opinion, there is really nothing mysterious or spectacular about a radiant system. Fundamentally, it is simply another method of using the long established mediums of either hot water or steam for heating purposes. It differs from the conventional systems mainly in that instead of using one or more radiators in a room, pipe coils are placed in the ceiling, floor, or walls to warm the surfaces and thus bring the temperature to a comfortable degree for the occupants.

Generally speaking, radiant heating is adaptable wherever conventional systems have been employed, i.e., in homes, schools, churches, office and public buildings, while certain special advantages are emphasized by its proponents for industrial buildings, shops, garages, and large areas where maintenance of uniform temperature is desirable, as well as minimum loss of usable space. Another large scale use of radiant systems is for the removal and prevention of snow and ice from airport runways, driveways, sidewalks, etc.

Both in this country and abroad some of the radiant heating installations have been made in quite large projects—for example, the Royal Liver Building in Liverpool. This sizable building contains one thousand rooms and the radiant heating system is said to be both efficient and economical in operation.

With the resumption of an active building program in this country advocates of radiant heating confidently predict this modern method will be extensively employed in both large and small structures of many different types. The home building program especially has already stimulated a wide and growing interest in the subject and will continue to receive considerable attention in numerous articles in various publications and in forum discussions in association or society meetings.

National Tube Company has been fully cognizant of the growing interest in this type of heating. Extensive study and investigation of all phases of the piping service have been and will continue to be made to the end that prospective users of radiant heating systems may have the benefit of the widest and most extensive experience available in all kinds of pipe problems, including radiant heating. The actual design of radiant systems, however, is properly the function of professional heating engineers. Their knowledge and experience in heating problems in general can be readily applied to any contemplated radiant installation. In matters pertaining to the piping proper, National Tube Company will gladly extend the fullest possible cooperation without charge or obligation.

What Is Radiant Heat?

RADIANT ENERGY

No better example of the phenomenon of radiation can be found than that of the sun in its energizing and heating of the earth upon which we live. It imparts to all living things radiant energy in the many forms necessary to a continuance of life.

The manner in which this energy is radiated from the sun is not definitely known, but it is believed that it reaches us through the medium of the ether, and in the form of wave motions of varying intensity and length. Many of us have thrown a stone into a quiet pool of water, and fascinated, we watched the first energy wave motion develop in the form of an ever widening circle, to be followed by many others at regular intervals. While wave motion from the sun is not apparent to the naked eye, the manner in which energy is transmitted by the sun is similar to the wave motion of the water. We must understand, however, that the energy radiated to us from the sun takes many forms, and each of these forms is identified by its wave length, which, to go back to our analogy, would be the distance from one circular wave to the one following. Energy waves of one length produce light with resultant color effects, as seen in a rainbow following a shower.

This bow of light has all the colors of a spectrum, brought about by dispersion and diffraction of light waves in the drops of water falling through the air.

Some short energy waves possess that property which can effect chemical changes, as evidenced by that coat of tan which is sometimes sought after during summer months; and in a less agreeable way, by the familiar souring of milk left too long on the kitchen doorstep. Energy of the longer wave lengths is utilized in connection with electronics, radio transmission, and radar.

Many other interesting effects are produced by radiation of energy from the sun but for the purpose of this discussion we are concerned only with that form and wave length of energy which is converted into heat upon contact with the earth's surface.

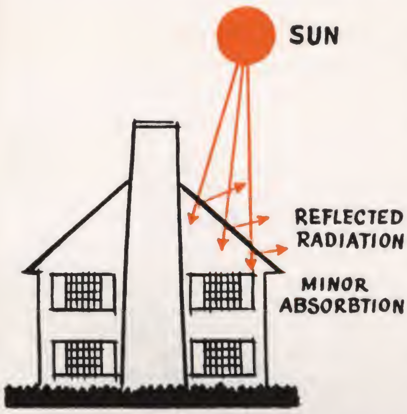
In discussing radiant heat and its manifestations, we must first dismiss from our minds the thought that either the open air around us, or that contained in a house or building, is heated by radiant energy waves. The air is not directly heated in this way, but does, in passing over surfaces which have absorbed radiant energy and converted it into heat, carry off a small part by convection.

HOW DOES RADIANT ENERGY BECOME HEAT?

Radiant heat energy waves strike all objects in their paths, and are either absorbed, or reflected to other objects.

If we were able to see with the eye of a microscope powerful enough and were to watch the effect of the impact between the waves of radiant energy transmitted from either the sun or a radiant heat panel on the plaster or woodwork in a room, we would witness an extremely interesting occurrence. We would observe that the infinitesimally small particles of plaster or wood called "molecules" were in a highly agitated state, vibrating in all directions at terrific speed, and striking one another an enormous number of blows per second. This has come about as a result of impact of the radiant energy waves on those molecules nearest the surface of the plaster or wood, and the impact has been transmitted in chain fashion to other molecules throughout the material. This impact of the molecules, one upon another, creates heat in the

plaster or wood just as effectively as does the impact of a steel hammer on some steel object.



An excellent example of the heat producing energy transmitted by radiating waves from the sun is found in the simple experiment of holding a magnifying glass over a piece of paper at a distance which permits the parallel energy transmitting rays of the sun to enter one side of the convex glass and converge upon the paper on the opposite side at the focal point, Figure 1. The concentration of radiant energy is sufficient to heat the paper until it ignites and burns.

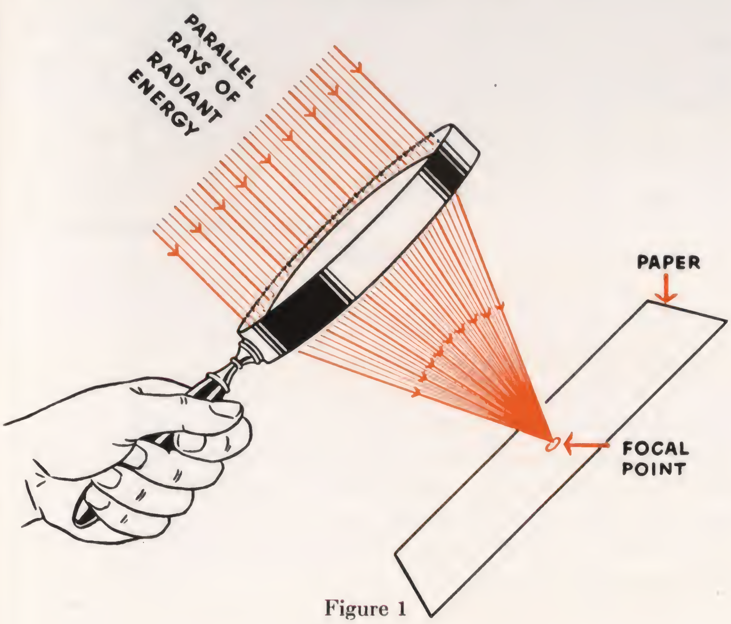


Figure 1

The energy or heat-creating waves from the sun, or from any other heating surface, are not all absorbed through the surfaces of the bodies upon which they impinge. Some strike bright metallic objects and the greater proportion of these are immediately reflected without being absorbed. Others reaching dull, dark-colored, lusterless substances are absorbed to a much greater extent. Thus, a substance which reflects heat well is a poor absorber of heat.

BRITISH THERMAL UNIT (B.T.U.)
THE MEASURE OF HEAT

The scientist, Dr. Joule, determined the relation between heat and energy by recourse to a well known experiment, Figure 2. He suspended a weight, which in its free descent rotated the drum and paddles, causing a churning action in the water.

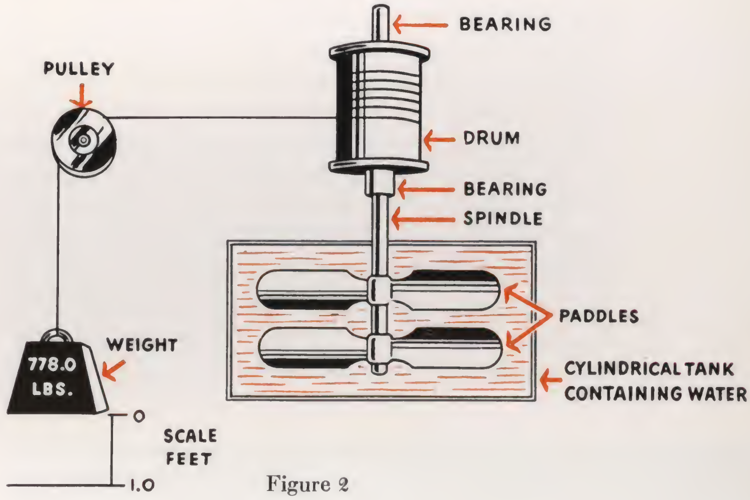


Figure 2

By this experiment Dr. Joule determined that when the weight of 778 pounds had fallen one foot, representing 778 foot-pounds of work done or ENERGY EXPENDED, the temperature of the water had increased by one degree Fahrenheit. He thus related heat, energy, and motion.

The result of this experiment is the basis for the "measure" of heat which is described as the British Thermal Unit (B.T.U.) and defined as "the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit."

HEAT-ENERGY RADIATION,
EVERYDAY OCCURRENCE

Many of us are familiar with the popular demonstration of the effect of the sun's radiant energy found in the illustrations of many of our magazines. These depict skiing enthusiasts enjoying this winter sport clad only in bathing suits, with the air temperature near freezing point. They are quite comfortable. This is possible because the velocity of the air is low, and the amount of heat carried off from the body by air convection currents is adequately offset by radiation of heat creating energy waves to the body from the sun. The snow aids considerably in creating this feeling of bodily comfort by reflecting much of this energy to the body surface of the skier.

Human Comfort, the Basis for Design of Radiant Heating

THE HUMAN BODY is a most remarkable heating unit, particularly when we consider the abuse to which it is subjected. We feed it fuel as we do a furnace in the form of food and drink. By a process called "metabolism" this fuel is converted into bodily energy and heat.

In the medical profession the heat measuring-unit is the "calorie," used to describe the heat and energy building value of various foods when absorbed by the human body, thus the term "calorific value of food."

Human beings require a constant replenishment of "caloric" or, similarly expressed, B.T.U. bearing foods to replace that heat or energy which is dissipated by physical exertion, by loss to surrounding bodies of lower temperature through the action of air convection currents passing over the body, and by evaporation. Science has established that the average human being, normally engaged in the daily activities, may lose heat at the rate of 400 B.T.U.'s per hour to surroundings at about 70° F. temperature, and in still air. Of this amount, 300 to 320 B.T.U.'s per hour may be lost by radiation and convection from the body surfaces, with the remainder being lost by evaporation of moisture from the lungs and the body surface, Figure 3.

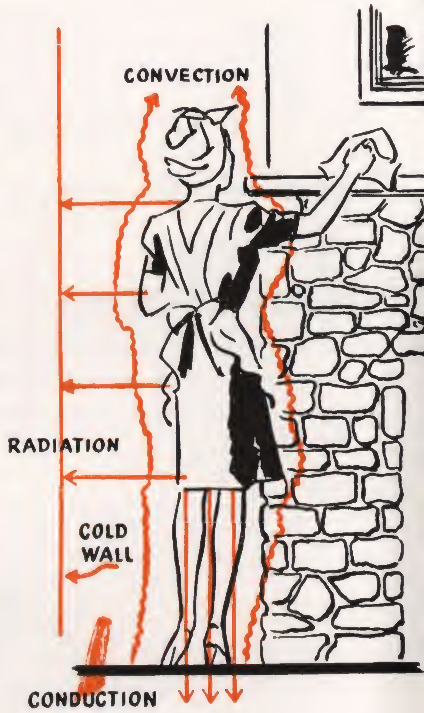


Figure 3

We have observed by the illustration of the skier in a bathing suit or light attire how it is possible for human beings to be comfortable, provided the heat lost by convection at low temperature is balanced by the radiation of heat to the body at higher temperature. Similarly, in heating a room, we may obtain a condition of comfort by a proper balance of wall surface temperature and room air temperature.

Dr. Yaglou, as a result of an investigation conducted at Harvard University with three male adults clothed in three-piece suits and at rest during the tests, found that conditions of comfort were obtained with the following three sets of temperatures* for which the bodily heat loss by radiation and convection is given:

Mean Radiant Temperature (M.R.T.) Deg. F.	Air Temperature Deg. F.	Heat Loss Radiation & Convection B.T.U./Hour
71	71	291
79	63	321
85	59	303

*Courtesy "Heating, Piping and Air Conditioning" and F. E. Giesecke, Consulting Engineer.

It is seen from the table that we can obtain a condition of bodily comfort with several combinations of room surface temperature and room air temperature. It is necessary only that the heat carried off by air convection currents be adequately

Skiing enthusiasts enjoy this winter sport clad in light attire with the air temperature near freezing point. Comfort is enjoyed because of radiation of heat creating energy waves to the body from the sun. The snow aids considerably in creating this feeling of bodily comfort by reflecting much of this energy to the body surface of the skier.

offset by reduction in the amount of heat lost by radiation to the room surfaces and thence by conduction through the building materials.

To do this we must heat the room walls, windows, doors, and floor, to a mean surface temperature such that these surfaces will reradiate to the body the greater part of the heat which it gives off by radiation.

The surface temperature of the average person varies between 80° F. and 83° F. If, then, the mean surface temperature of the room, or as it is technically termed, the mean radiant temperature, is established for design purposes at 75° Fahrenheit, the heat loss from the human body to these same surfaces by radiation will be small.

The chart,* Figure 4A, shows that approximately 50 B.T.U.'s per hour are lost from the body by radiation, when the average body surface temperature is assumed to be 80° Fahrenheit. This leaves (320-50) = 270 B.T.U.'s per hour, which we are permitted to lose by convection before a feeling of discomfort is felt.

Referring to Figure 4B we find that the equivalent air temperature for this heat loss is 65° Fahrenheit, and that theoretically the air temperature may reach this value before discomfort is felt. In actual practice however, as in the heating of a home, the air temperature and the mean radiant temperature may approach equilibrium, due to contact of the air with the heating surface, and we are more likely to obtain an air temperature differing by only a few degrees or so from the mean radiant temperature. For a comfort temperature of 70° F. we may expect the mean radiant temperature to be 72° F. and the air temperature 68° F.

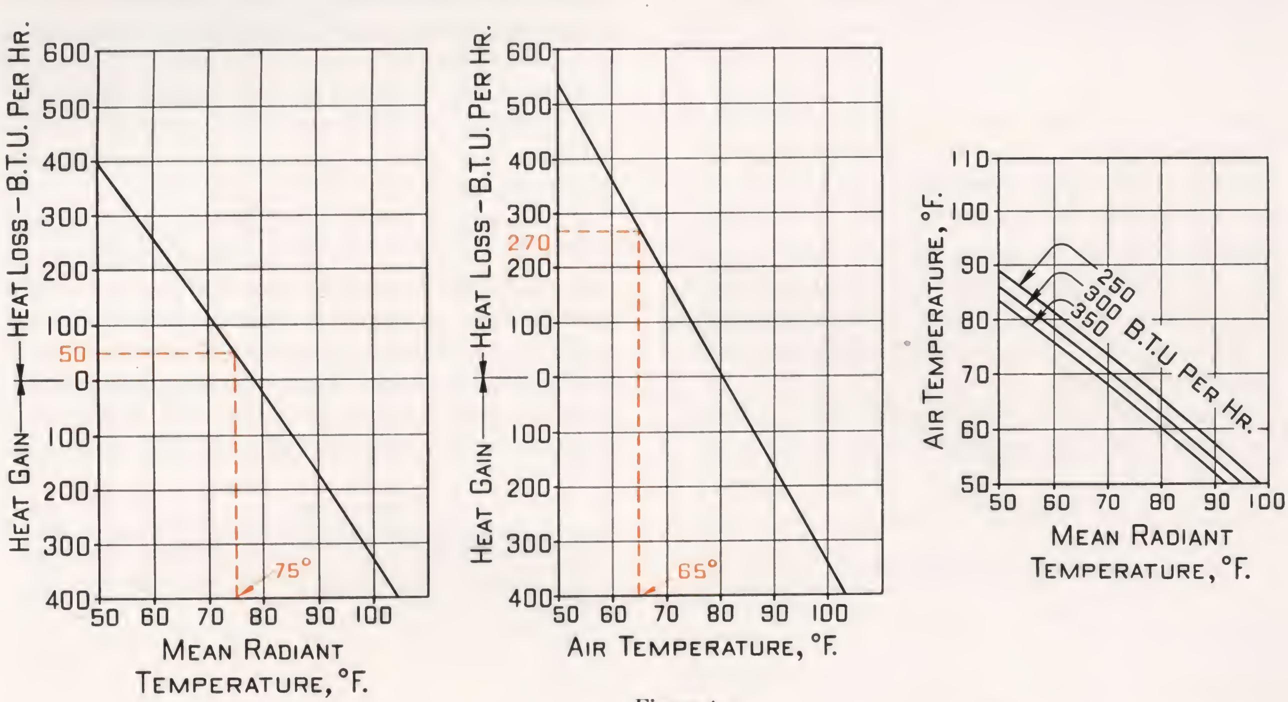


Figure 4

A—Heat loss or gain by radiation for various mean radiant temperatures, in Btu per hr. per person, according to the formula $Q = 15 \times 0.156\,[(540/100)^4 - (T_r/100)^4]$, where 15 sq. ft. is the area of the body available for radiation, 0.156 is the radiation factor for the body, 540 is the absolute mean surface temperature of body (460 + 80), T_r is the absolute mean radiant temperature of the room, and Q is amount of heat, Btu per hr. per person.

B—Heat loss or gain by convection for various air temperatures, in Btu per hr. per person, according to the formula $Q = 18 \times 1\ (80 - t_a)$, where Q is Btu per hr. per person, 18 sq. ft. is the area of the body exposed to convection air currents, 1 Btu per hr. per sq. ft. per ° F. temperature difference is the film coefficient, 80° F. is the mean surface temperature of the body, and t_a is the temperature of the air in the room in degrees Fahrenheit.

C—Relationship between air temperature and mean radiant temperature for combined convection and radiation heat losses of 250, 300, or 350 Btu per hr. per person, as indicated on curves.

*Courtesy "Heating, Piping and Air Conditioning" and F. E. Giesecke, Consulting Engineer.

Some Temperature Studies in Radiant Heated Rooms†

HAVING CONSIDERED THE VARIOUS POINTS relating to heat requirements and how the heat can be applied, we are now in a better position to consider what are the requisites of a good system of heating and ventilating. Dr. Leonard Hill, and also the Industrial Fatigue Research Board of England, laid it down that a good system should provide an air temperature at the foot level equal to that at the head level, if not greater. There should be a fair degree of air movement and the air should not smell stuffy and unpleasant. This compares with nature's provisions for heat supply where we find that rays from the sun, with the long waves reflected from the earth and surrounding objects, warm the lower strata of moist air from our feet upward and give that ideal condition which our bodies require. The nearer we approach these conditions, the more closely we attain the ideal method of heating.

We have seen that, if an installation is to give the required degree of comfort and meet the physiological requirements of the body, a large percentage of the heat must be supplied as thermal radiations, and the relative humidity of the air should be maintained somewhere between 50% and 60%, preferably the latter.

Most of the heat should be given off by thermal radiations, with the remainder as convected heat.

Ordinary radiators may give off as little as 10% to 20% of their heat by thermal radiation and the remainder as convected heat, while with concealed heaters, unit heaters, and warm-air systems we get no thermal radiation whatever, except the secondary action from the furniture. Since all the objects in a room are at a lower temperature than the surrounding air, and consequently at a lower temperature than our bodies, we get no supply of energy from these sources.

Figure 5 illustrates diagrammatically the conditions we generally obtain with a concealed heater or a warm-air system. Assume that steam is turned on and a stream of warm air is introduced into the room from the grille or from the top of the concealed heaters. From concealed heaters the temperature of the air may be 130° F. to 150° F., although I have actually measured the air temperature leaving the grilles as high as 190° F.

With a warm-air system the inlet temperature may be as high as 180° F. to 200° F. This warm air is not only detrimental to the system, but, having passed over a high temperature surface, it has become polluted, for when the air passes over a surface at high temperature the dust is broken down chemically and ammoniacal vapors given off. With steam radiators we get similar results, but the air leaving

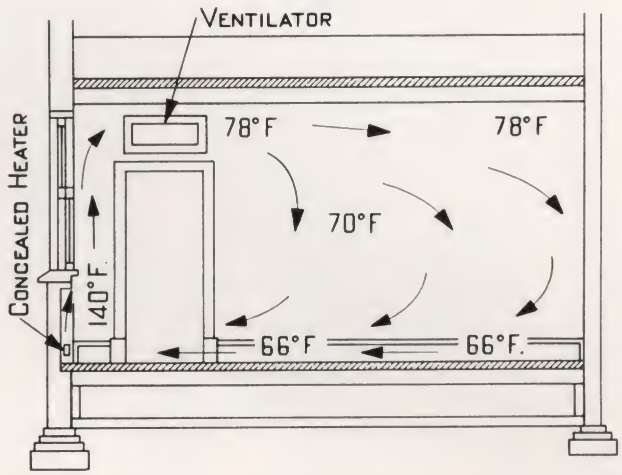


Figure 5. Temperature distribution in a room heated with a concealed heater or a warm-air system.

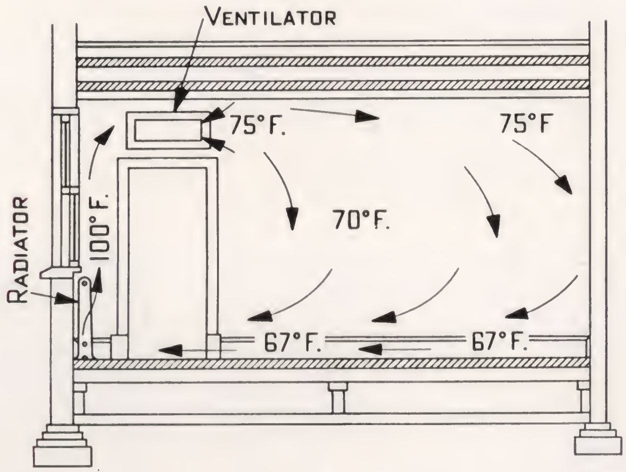


Figure 6. Normal temperature distribution with a steam radiator. Average observations in rooms of 9 to 10 ft. in height.

†By T. Napier Adlam, Consulting Engineer, Member of Institution of Heating and Ventilating Engineers, Great Britain. Reprinted from "Heating and Ventilating" by courtesy of the publisher, and of the author, Mr. Adlam.

the top of the radiator will be 90° F. to 110° F., depending on the room temperature.

In either case the warm air naturally rises to the ceiling and will remain there, giving up part of its heat to the cold ceiling, and should there be any outlet at the high level the warmest air will escape before being of further use. As more warm air rises from the source of supply, the air at the ceiling, which does not escape, chills gradually. This continues until we get a series of layers at different temperatures. In other words, we have a temperature gradient from ceiling to floor.

The steepness of this temperature gradient will depend on the temperature of the air rising from the source, the heat loss from the room, and the quantity of air which is circulating.

TEMPERATURE DIFFERENCE OF 6° F. TO 14° F. NOT UNUSUAL WITH CONVECTED HEAT

When using steam pipes and radiators it is usual to get from 6° F. to 8° F. difference in temperature between the floor and the ceiling. With warm air or concealed heater I have found a difference of 10° F. to 14° F. to be quite common. Figure 6 illustrates diagrammatically the normal conditions met with in a room heated by steam radiators. These are average observations in rooms from 9 ft. to 10 ft. high. For higher rooms the temperature at the ceiling will be correspondingly higher.

Figure 7 shows average recorded temperatures at various heights for heating with radiators and convectors, and it will be clearly seen that the high temperature gradient means greater loss of heat.

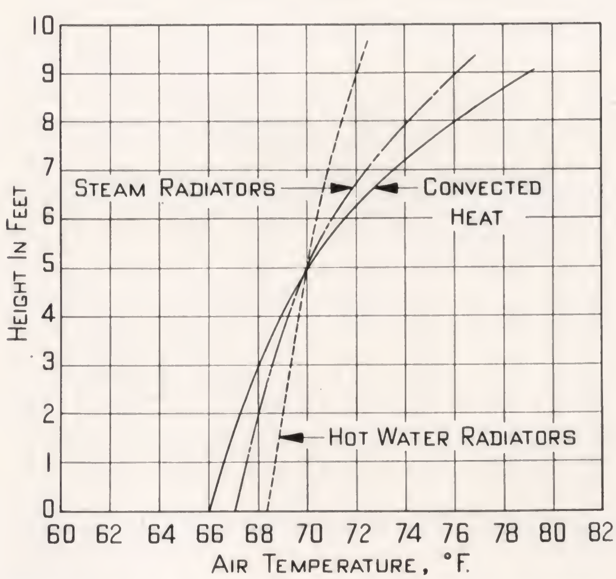


Figure 7. Average reported temperatures at various heights for heating with radiators and convectors.

We find a warm stratum of air for breathing and for the head, with a cooler temperature for the feet, just the opposite to that required.

I have taken observations in many of the high buildings in this country and find that air is constantly passing through the ventilators over the doors into the corridors or passages at a temperature five or more degrees above the temperature of the air at the breathing line. This chimney effect in tall buildings is a bugbear to all heating engineers and architects because of the difficulty of being able to overcome its influence. The graduation of heating surfaces is only a partial remedy, for it does not hold good under all weather conditions.

Compare this with a building heated with thermal radiations where the air temperature at the high level varies only slightly from that at the breathing line. The result, as can be seen by Figure 11, would be an almost constant temperature throughout the building.

MEAN SURFACE TEMPERATURE DEPENDS ON CHARACTER OF SURFACE

It has been computed that if the mean surface temperature all over a room is about 60° F. the room feels warm, regardless of the air temperature. This, however, depends on the character of the surface. If the surface is covered with tinfoil or a highly polished metal surface, the results would be infinitely superior from a heating point of view than it would be if we had a dull black surface or even the usual papered surfaces.

Much has been written as to the best method of producing these heat rays, the relative virtues of ascending and descending rays, and the best temperature at which the surface should be maintained, but invariably it will be found that the respective advantages are illuminated according to the particular system advocated. Undoubtedly they all have advantages, and it is by correct discrimination that heating engineers can choose the best method for the particular problem in hand.

At present we will deal with each method diagrammatically, and later each system in use will be explained in detail. In Figures 8, 9, and 10 we have indicated a room heated by thermal radiations with rays emitted from a heated floor, ceiling, and walls respectively.

Figure 8 shows a heated floor of a room made with

any material ordinarily used for flooring, except material which is likely to become plastic with heat, such as wood blocks bedded in pitch, etc. Wood, stone, marble, concrete, or other composite material may be used, and carpets may be laid on the floor without interference with the heat. In fact a carpet adds greatly to the comfort, for a heated floor covered with a thick carpet has given to the writer the best impression of real comfort of any heated room yet tried.

The required surface temperature of the floor varies with the kind of surface used and also with the exposure of the room. For instance, in testing out various materials I have found when trying white marble, which was to be used for the floor of Liverpool Cathedral, that with the polished white surface of the marble I required a surface temperature of 11° F. above the air temperature to give off a certain quantity of heat. I could obtain the same results with a surface temperature of 8° F. above the air temperature when the marble was covered with a thin coating of lamp black.

HIGHER TEMPERATURES DESIRED IN THIS COUNTRY THAN IN ENGLAND

I should explain that in England it is found, generally speaking, that while 60° F. is a suitable air temperature with radiators and pipes, an equal feeling of comfort is obtainable at 56° F. to 58° F. with thermal radiations. In this country, however, it is desirable to have a higher room temperature than in England for several reasons.

In the first instance, people in this country evidently wear lighter undergarments and therefore rely more on artificial heat. Too, in this country they do less outdoor exercise and consequently the physiological heat generator will not function so readily as with people in England. The air, without doubt, is dryer, and consequently a higher temperature compensates for this.

Many years of living in a higher artificial temperature has had its effect upon the system, and as through the ages and process of evolution environment has changed life and custom, so I think in this country the metabolism of the average American is now demanding higher temperature to make up for the conditions to be met.

During cold weather I have as a test condition been in my office and worked in perfect comfort while my colleagues had to resort to their overcoats to keep themselves sufficiently warm, which proves that it is not so much the climate, but the gradual acquisition by continual use. I keep careful records and find that I require one or two degrees higher temperature than when I first came to this country.

Therefore, in dealing with the application of thermal radiations I am taking a basic temperature of 64° F., as I find that this temperature with a relative humidity of 50 gives to my friends here a very real sense of comfort.

Referring to Figure 8, it can be seen that we get from the heated floor a stream of thermal radiations passing upward over the whole area, or from that portion of the floor which we choose to heat.

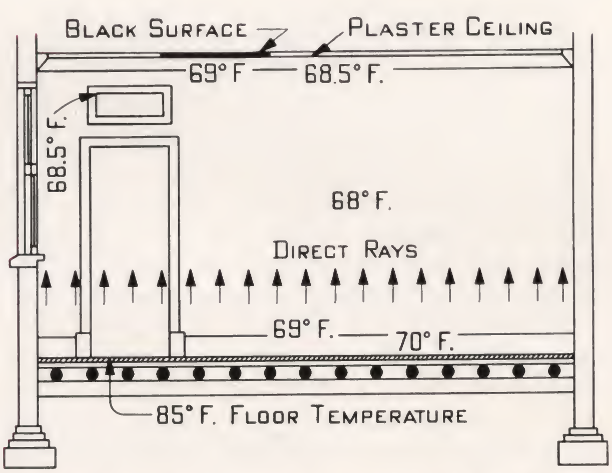


Figure 8. Room with heated floor made of ordinary flooring material, showing temperature distribution.

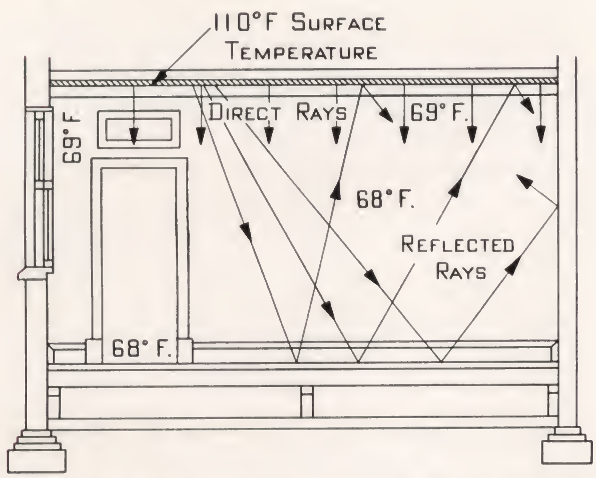


Figure 9. Room warmed by a heated ceiling, showing the manner in which radiant rays are reflected.

"The temperature of floors in Radiant Heating Systems is in the temperature range of 75° F. to 85° F. and the health of children using floors to play on is thus safeguarded" (see page 28).

WOOD FLOOR TEMPERATURE TO BE 16° F.-18° F. ABOVE INDOOR AIR TEMPERATURE IN SEVERE WEATHER

For maintaining the conditions stated before with an ordinary wood floor I find a surface temperature of 16° F. to 18° F. above the air temperature is necessary in extreme weather conditions. In milder weather 12° F. will suffice. This, however, is with an abnormal amount of glass exposure and with an exposed flat roof in addition. The range of temperatures recorded is indicated in Figure 8 and also in Figure 11.

It is interesting to note that in Figure 8 the temperature 4 inches above the floor is but slightly higher than that at the breathing line, and so also is the air temperature 1 inch below the black portion of the ceiling. A portion of the ceiling was purposely made black to study the effect. The black surface absorbs the rays received from the floor and its temperature is raised slightly above the air temperature. Now the molecules of air in direct contact with the warmer surface receive heat by conduction, and immediately the molecules are set into vibration and rebound from the surface for a short distance, depending on the impulse received.

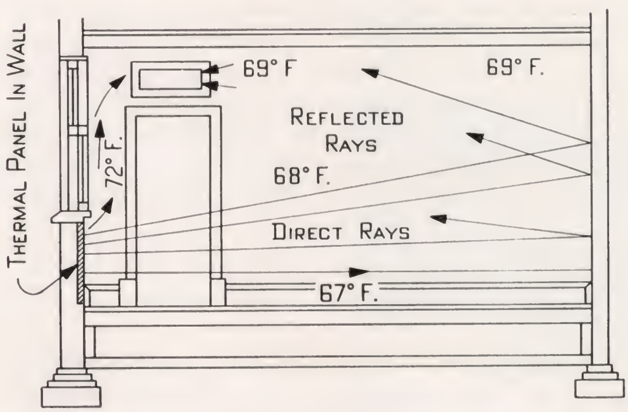


Figure 10. Room heated with thermal radiations from heated surface on side walls.

RADIOMETER DEMONSTRATES ABSORPTION BY BLACK SURFACE

We may have a demonstration of this effect any time we stop at an optical store or a jeweler's, where a radiometer is on display. This instrument is usually constructed with two glass bulbs one above the other. In each of these bulbs there are four platinum vanes mounted on a light framework, which is pivoted on a needle point. One side of each vane is highly polished and the opposite side is coated with lamp black. The glass vessels are exhausted so that the air is very rarified and offers little resistance to movement. When a stream of rays impinges on the vanes they revolve so that the polished surfaces take the lead in the direction of the rotation. Energy is absorbed by the black, and reflected by the polished surfaces. The blackened surface naturally rises in temperature and the

residual air is heated and, in terms of the kinetic theory, the air molecules striking the hot surface rebound with an augmented velocity. This reactive force on the black side causes the vanes to revolve.

With floors and ceilings, which are fixed, we get the effect of fixed surfaces, but with a continuation of discharging warm molecules of air driven away from the surfaces to a distance sufficient to absorb the energy. Hence we get a slightly higher air temperature near all heating surfaces, for a distance varying with the force given to these molecules.

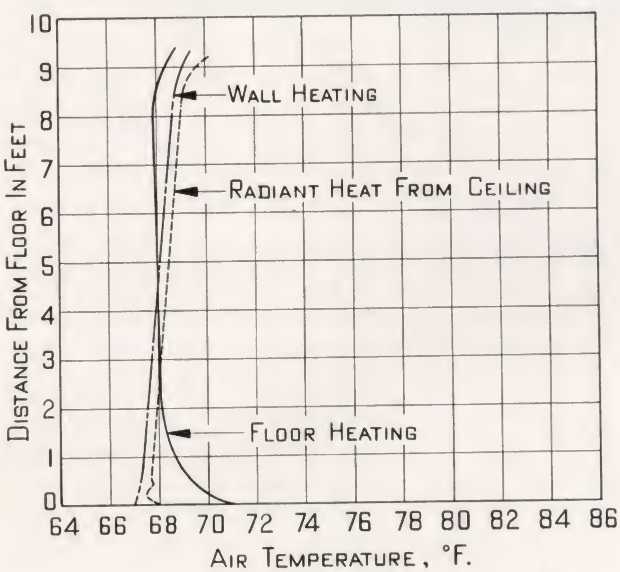


Figure 11. Comparison of results with radiant heating from ceiling as compared with wall and floor radiant heating.

In Figure 9 we have a room warmed by a heated ceiling. The rays descend from the ceiling, and if not intercepted by furniture or other obstacles will impinge on the floor and have the same effect on the floor as the heated floor, Figure 8, has on the ceiling.

The disadvantage with this method is that anyone sitting at a desk or table will have his legs and feet screened from the rays, while the head and shoulders will receive the full shower of rays direct from the ceiling.

RADIANT HEAT FROM SIDE WALLS HAS SOME ADVANTAGES OVER OTHER METHODS

Figure 10 shows a room heated with thermal radiations given off from a heated surface placed on the side walls. When so placed we get a larger amount of convected heat than we do when either the floor or ceiling heating is used. On the other hand, we shall find in dealing with the details of the schemes that this method holds many virtues which the others do not.

The amount of convection obtained from the side wall surfaces amounts to about 40% to 50% of the total heat given off. The heat rays are given off horizontally, but with all unpolished surfaces we get an irregular surface, which has the property of sending out rays from all its facets. This means that rays are emitted at all angles, and with the reflected rays from other surfaces the room is filled with a shower of rays from all directions. A disadvantage of this method is that a large piece of furniture placed in front of the heated surface will annul its effect, but we should no more think of putting an article of furniture against the heating panel than we should of placing it so as to cover up the window or the door.

If we know the heating panel should be placed in a certain position and left exposed, why not have the courage of our convictions and say it must be so, in the same way as we would a window or an electric light. We can, of course, place the heating panel under the windows and, if sufficient surface can be installed, this makes a very admirable place, for the convected heat given off is well able to deal with the exposure of the window. The rays impinging on the opposite wall and those reflected will warm up the whole room, but care naturally must be taken to obtain full advantage of all the reflected rays, for by so doing great economy is effected.

RADIANT HEATING APPROVED BY BRITISH INDUSTRIAL FATIGUE RESEARCH BOARD

With the small amount of convected heat given off, we obtain a current of warm air spreading itself over the ceiling which takes care of the heat loss through the ceiling, as it is apparent that with vertical radiant surfaces we do not get the rays impinging on the ceiling as we do in the other two systems. Speaking as a whole, however, it is the considered judgment of the British Industrial Fatigue Research Board that the thermal radiation method of heating gives a much more even temperature than does heating with radiators or with warm air.

This is even more true in this country than in England, for I find here, with the more extreme conditions and the different methods of construction, a greater variation in temperatures through-

out the room with radiator heating than is the case in England.

With very large rooms with a high exposure factor it would add considerably to the comfort to have a combination of floor and wall heating. It is invariably found that the occupants in such a place will complain of cold feet even though the air is overheated. This is due to the screening effect of all heat, either radiant or convected, the cold floor, and no doubt a slow current of cool air moving over the whole floor surface. If the floor was raised to a temperature of say 6° F. to 8° F. above the air temperature and the additional heat added by wall panels, the effect would be ideal.

Estimating Heat Losses From Homes

BASIC TO THE DESIGN of all heating systems is the determination of heat loss from the building.

Heat is lost continuously by conduction through, and radiation from, the walls, windows, roofs, and doors of the home or other building being heated.

The amount of heat lost depends upon the extent to which the building has been insulated and the difference between the desired room temperature and the temperature outside the building.

The measure of heat loss from a building or from the room of a building is obtained by the following formula:

$$H = AU\,(t_i - t_0)$$

Where H = Heat loss in B.T.U.'s per square foot per hour through a wall, floor, roof, door, or other part of a structure.

A = Area of the surface through which heat is lost. Square feet.

U = Transmission coefficient, or the heat loss in B.T.U.'s per hour per degree difference between inside and outside temperatures, through the combination of building materials from which, for example, the outside walls are to be built.

t_i = Inside room temperature. °F.

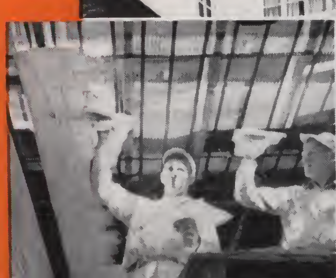
t_0 = Outside air temperature. °F.

The heat loss coefficient U has been established for many combinations of building materials, and may be found on pages 41 to 45 of this Bulletin. For example, the value of U for a wall, consisting of wood siding or clapboard and 1-inch wood sheathing on the outside, and having ½-inch plaster on wood lath on the inside, is given as 0.24 B.T.U.'s per square foot per degree difference in temperature (page 43).

If the desired room temperature is 70° F. and the lowest outside air temperature in the region in which the building is to be erected is assumed as zero degree F., the total heat loss per square foot of building surface will be

(70° F. − 0° F.) 0.24 B.T.U.'s/hour.

A total of 4,000 feet of NATIONAL Steel Pipe was used for the radiant heating system in the residence of Jack Pahl, eastern San Francisco Bay area, California.



Interior view of the Jack Pahl residence, showing ceiling coils being covered with plaster.

To determine the total heat loss from a room requires only that the entire surface areas for other combinations of materials be multiplied by their heat loss rate in B.T.U.'s per hour.

Where the values of U for the combinations of materials which the plans call for in the walls, roofs, etc. are not given in the Heat Transmission Tables, they may be calculated by the equation

$$U=\frac{1}{\frac{1}{f_1}+\frac{1}{f_2}+\frac{x_1}{k_1}+\frac{x_2}{k_2}+\frac{x_3}{k_3}}$$

Where f_1 = coefficient of heat transfer between the inside wall surface and the still inside air of the room.

f_2 = coefficient of heat transfer between the outside wall surface and the moving outside air.

f_1 and f_2 are expressed in B.T.U. per hour per square foot of surface per degree Fahrenheit temperature difference between air and wall surfaces.

x_1, x_2, and x_3 = thicknesses of material composing the wall, ceiling, etc.

k_1, k_2, and k_3 = coefficient of thermal conductivity of the materials expressed in B.T.U. per square foot of surface area per inch of thickness per degree Fahrenheit difference in temperature per hour.

When air spaces exist between materials, the formula must be modified to accommodate the factor a which defines the heat transmitted across the air space between materials, expressed in B.T.U. per square foot or surface area per hour per degree Fahrenheit difference in temperature.

The formula then becomes:

$$U=\frac{1}{\frac{1}{f_1}+\frac{1}{f_2}+\frac{x_1}{k_1}+\frac{x_2}{k_2}+\frac{x_3}{k_3}+\frac{1}{a_1}+\frac{1}{a_2}}$$

It becomes apparent that any change in the number of layers of material or in the air spaces between materials affects the number of factors k, or a in the formula. Values for these factors may be found on page 41.

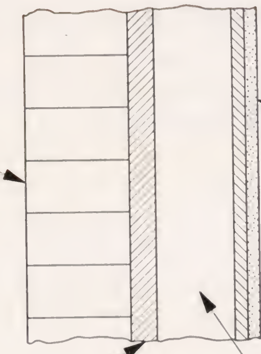


Figure 12

EXAMPLES OF THE USE OF FORMULAE

What is the coefficient of transmission air to air for the wall of a house as illustrated in Figure 12, assuming an outside wind velocity of 15 miles per hour? Use values of heat conductivity given on page 41.

$$U=\frac{1}{\frac{1}{f_2}+\frac{x_1}{k_1}+\frac{x_2}{k_2}+\frac{1}{a_1}+\frac{x_3}{k_3}+\frac{x_4}{k_4}+\frac{1}{f_1}}$$

$$=\frac{1}{\frac{1}{6.0}+\frac{4.0}{5.0}+\frac{1}{0.80}+\frac{1}{1.1}+\frac{1}{2.82}+\frac{0.5}{3.3}+\frac{1}{1.6}}$$

$$=\frac{1}{0.166+0.8+1.250+0.909+0.354+0.151+0.625}$$

$$=\frac{1}{4.255}=.23$$

EXAMPLE

What is the heat loss through the wall of a room of such material, assuming the area of the wall to be 8 feet high by 22 feet long, the inside temperature 70° F., the outside design temperature zero degree Fahrenheit?

$$H=AU\ (t-to)$$
$$=8\times 22\times 0.23\ (70-0)$$
$$=2834 \text{ B.T.U.'s per hour.}$$

ESTIMATING HEAT LOSS FROM A ROOM

The total heat loss from a room is equal to that lost through walls, floor, ceiling, doors, and windows plus that due to infiltration of cold air.

EXAMPLE

What is the heat loss from the living room of a bungalow type house, without basement, which is to be heated by radiant heat from a concrete floor panel? See Figure 13.

DESIGN DATA

Outside design temperature = 0° F.
Inside living room temperature = 70° F.

Temperature of space between living room ceiling and roof assumed as mean of room and outside temperature = 35° F.
Initial heat loss to ground during period of warming up of panel may be assumed as 20 per cent of all other heat losses from room. Assume infiltration loss equal to one air change per hour for residences.

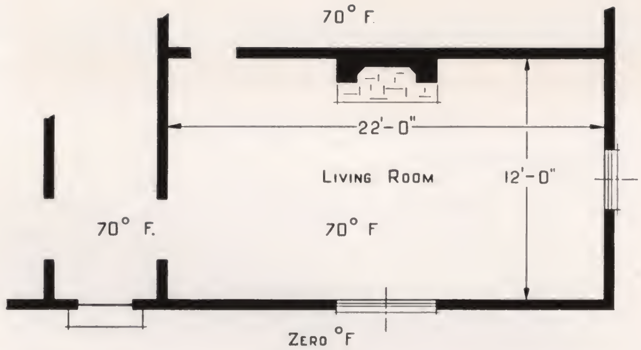


Figure 13

LIVING ROOM HEAT LOSS CALCULATIONS

Room dimensions feet	Building materials	1 Net area sq. ft.	2 Transmission coefficient U	3 Temperature difference	1×2×3 Heat loss B.T.U.'s/hr.
Exposed wall 8×22	As per Figure 12	155	0.23	70	2496
Window 3.5×6	Single—storm (See page 46)	21	0.45	70	661
Exposed wall 8×12	As per Figure 12	87.25	0.23	70	1405
Window 2.5×3.5	Single—storm (See page 46)	8.75	0.45	70	276
Ceiling 12×22	Item 60, page 43	264	0.066	35	610
Heat loss by air change method* = 8×12×22×0.018×70				=	2661
		Heat loss, sub-total		=	8109
Initial heat loss to ground = 20 per cent of sub-total				=	1621
		Total heat loss		=	9730

*The Heating, Ventilating and Air Conditioning Guide 1945 states that "An allowance of one air change per hour for all sources of air leakage for the entire volume may be considered average for a well-constructed residence."

Concrete being applied on dining room, kitchen, and bedroom floor panels of residence of Elmo Hall, prominent radiant heating authority in Denver, Colorado. Living room coils in foreground.

Estimating Radiant Heating Coil Requirements—Floor Panel

(UTILIZING ENTIRE FLOOR AREA FOR PANEL)

SIMPLIFIED PROCEDURE

Living Room Coils

1. Determine the total heat loss from the room. Heat Loss = 9730 B.T.U.'s per hour, from page 15.
2. Divide the total heat loss by the entire floor area of the living room to determine the heat transfer rate in B.T.U.'s per hour per square foot of surface required from the concrete floor heating panel.
   Area of floor = $12 \times 22 = 264$ square feet.
   Heat transfer rate = $9730/264 = 37$ B.T.U.'s per square foot of surface.
3. Make a diagrammatic layout of the coils to be used, based on recommended spacing, using 1-inch standard pipe for residences. Measure off the pipe length. See Figure 14.

Coil Spacing and †Heat Transfer Rates When Installed in Concrete Floors or Plaster Ceilings

Standard pipe size inches	Spacing inches	Heat transfer rate C
½	6 to 8	0.8
¾	9 to 12	1.0
1	12 to 16	1.2
1¼	15 to 20	1.4

†Heat transfer rate is B.T.U. per foot of pipe, and per degree difference in temperature between hot water in coils and room air.
The transfer rate C will vary, depending on the depth of the pipe below the panel surface.
Table values are for a depth of approximately 3 inches below surface.

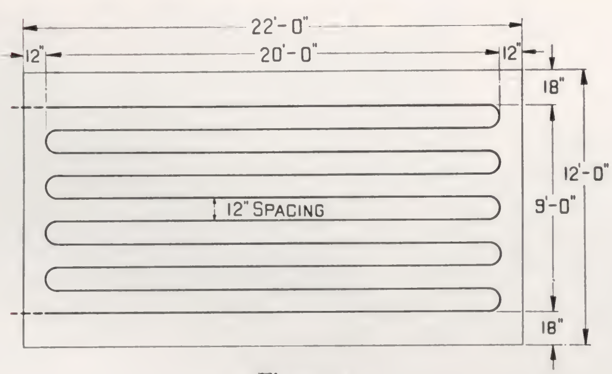


Figure 14

4. Determine the water temperature required in the coil to obtain the heat transfer rate of 37 B.T.U.'s per hour.

Required water temperature may be obtained from the formula—

$$t_w = \frac{H_t \times F_a}{C \times L} + t_r$$

Where t_w = mean water temperature in coils
t_r = room air temperature
H_t = heat transfer rate from heating panel in B.T.U.'s per hour per square foot of panel surface
F_a = floor panel area
C = a constant (see accompanying table of coil spacing and heat transfer rates) for 1-inch standard pipe $C = 1.2$
L = length of the heating coil in feet

For this example mean water temperature is

$$t_w = \frac{37 \times 264}{1.2 \times 205} + 70 = 40 + 70 = 110° \text{ F.}$$

The water temperature in the hot water line to the coils should therefore be $110 + 5 = 115°$ F. and in the return line to the boiler $110 - 5 = 105°$ F. The temperature difference as related to quantity flow provides a check on the total heat input.

5. Estimate the quantity of water to be pumped through the coils to give the required heat transfer per foot. This is governed by the water temperature drop desired in the radiant heating coils.
   Customary practice is to design for a temperature drop of 10° F. to 20° F., and in this example 10° F. is used.
   The quantity of water to be pumped through the coil is given by—

$$Q = \frac{H}{480\ t_d}$$

The bending quality of NATIONAL Steel Pipe is one of the major reasons for its outstanding preference wherever bending is required. Here it is being bent preparatory to installation on ceiling rafters of a residence.

Where Q = quantity of water in gallons per minute
H = total heat loss from room B.T.U.'s per hour
t_d = desired water temperature drop

$$Q=\frac{9730}{480\times 10}=2.0 \text{ gallons per minute}$$

6. Determine the friction loss in the coils for the required flow capacity. Referring to Chart, Figure 15, the friction loss per 100 feet of 1-inch standard pipe is 0.35 feet.

Length of straight pipe in the coil is 191 feet.
Number of bends is 9.

Assuming that the coil bends offer frictional resistance corresponding to straight pipe equal in length to 25 times the pipe diameter, the total equivalent length of pipe is—

$$\text{Length of straight pipe} + \frac{\text{No. of bends} \times 25 \times \text{pipe diameter}}{12}$$

$$= 191 + \frac{9 \times 25 \times 1.0}{12} = 219 \text{ lineal feet}$$

Total friction loss in the coils is $2.19 \times 0.35 = 0.77$ (approximately one foot).

After the total heat loss for the house has been determined in the manner outlined, and the total friction loss through all coils, valves, and fittings determined, the type and capacity of circulating pump to be used can be determined.

TESTING COILS

All coils after being fabricated and welded on the job should be subject to an air or hydrostatic test pressure of 250 pounds per square inch for a period of twelve hours, or to a test pressure and for a testing period, stipulated by the heating engineer.

USE OF CHART, FIGURE 16, TO ESTIMATE RADIANT HEATING COIL REQUIREMENTS —FLOOR PANEL

1. Determine heat loss from room.
   Heat loss = 9730 B.T.U.'s per hour, from page 15.
2. Assume a water temperature for the radiant heating coils of 110° F. (previous example).
3. Obtain the difference between water and room air temperatures, using water temperature from previous example.
   Temperature difference is $(110-70)=40°$ F.
4. Assume 1-inch standard pipe size, and using the estimated heat loss of 9730 B.T.U.'s and the temperature difference of 40° F., read off the length of pipe required for the coil, 205 feet.

NOTE:—The Chart, Figure 16, is based on a heat transmission value for residences of relatively low ceilings as encountered in usual construction of 3.5 B.T.U.'s per square foot of external pipe surface, per degree Fahrenheit temperature difference (td) water to air. The maximum desirable water temperature is approximately 130° F.

The values are governed by the depth of pipe below panel surface, and by the material from which the panel is constructed. The values given are for general concrete floor design, with pipe 3 inches below panel surface.

RESISTANCE OF VALVES AND FITTINGS TO FLOW OF FLUIDS*

When the flow of a fluid in a pipe line is altered by some obstruction, such as a valve or fitting, the velocity is changed, turbulence is magnified, and a drop in pressure results. This pressure drop may be insignificant in long lines where it is very small in comparison to the total drop, but when the line is short, the pressure drop through valves and fittings becomes a major item in the total pressure drop value.

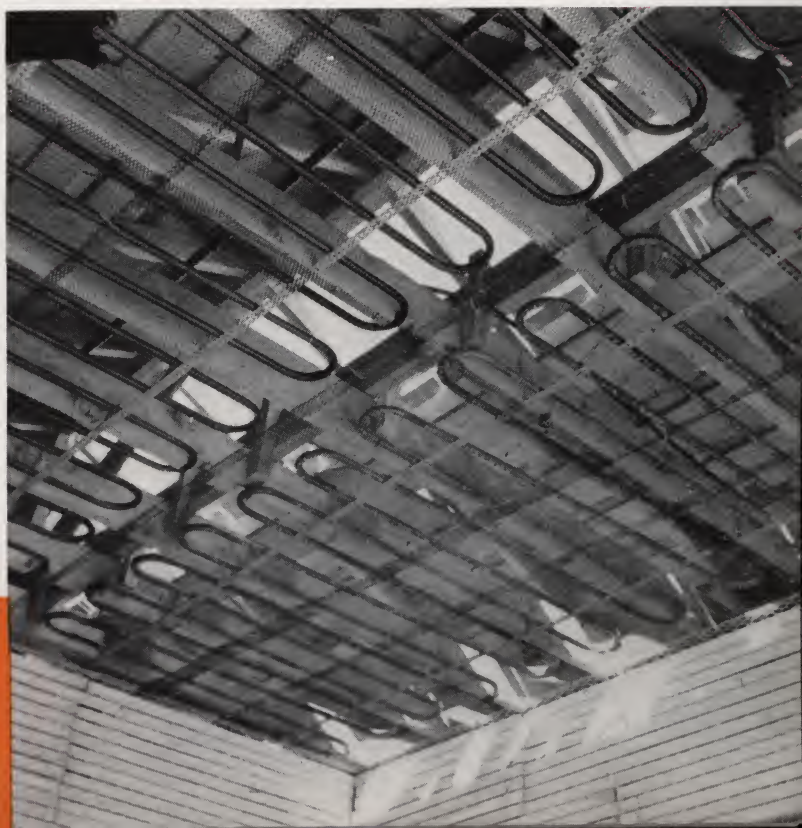
It has been shown by previous investigators that the drop in pressure through valves, fittings, etc., is some constant multiplied by the velocity head, $\frac{V^2}{2g}$.

Therefore,

$$H_1 = k\frac{V^2}{2g},$$

where H_1 = loss of head in feet
k = coefficient (values given in table on page 18)
V = velocity of water, feet per second
$2g = 64.4$

*Courtesy—Crane Co.



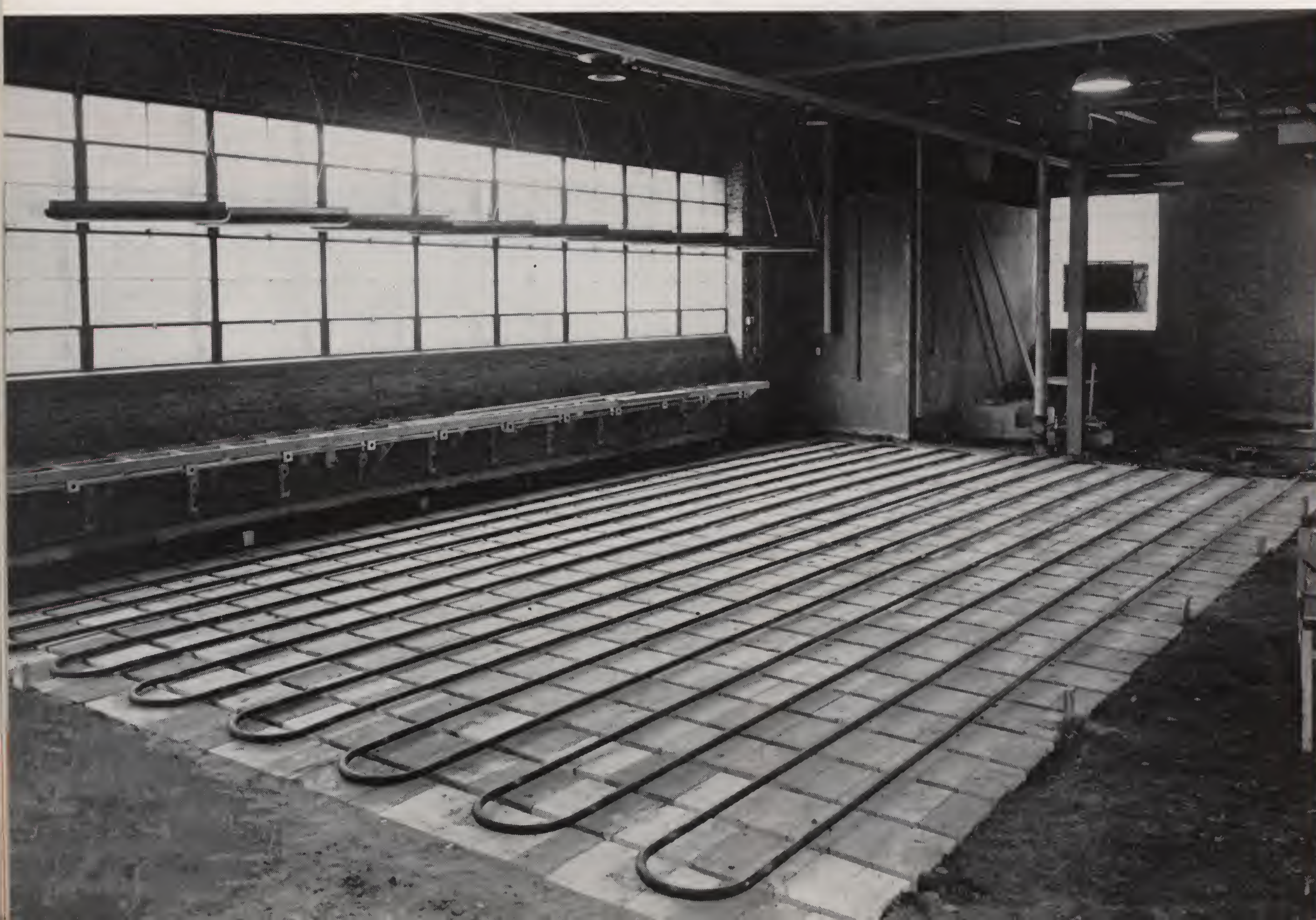
Typical ceiling coil installation of NATIONAL Steel Pipe in a California residence.

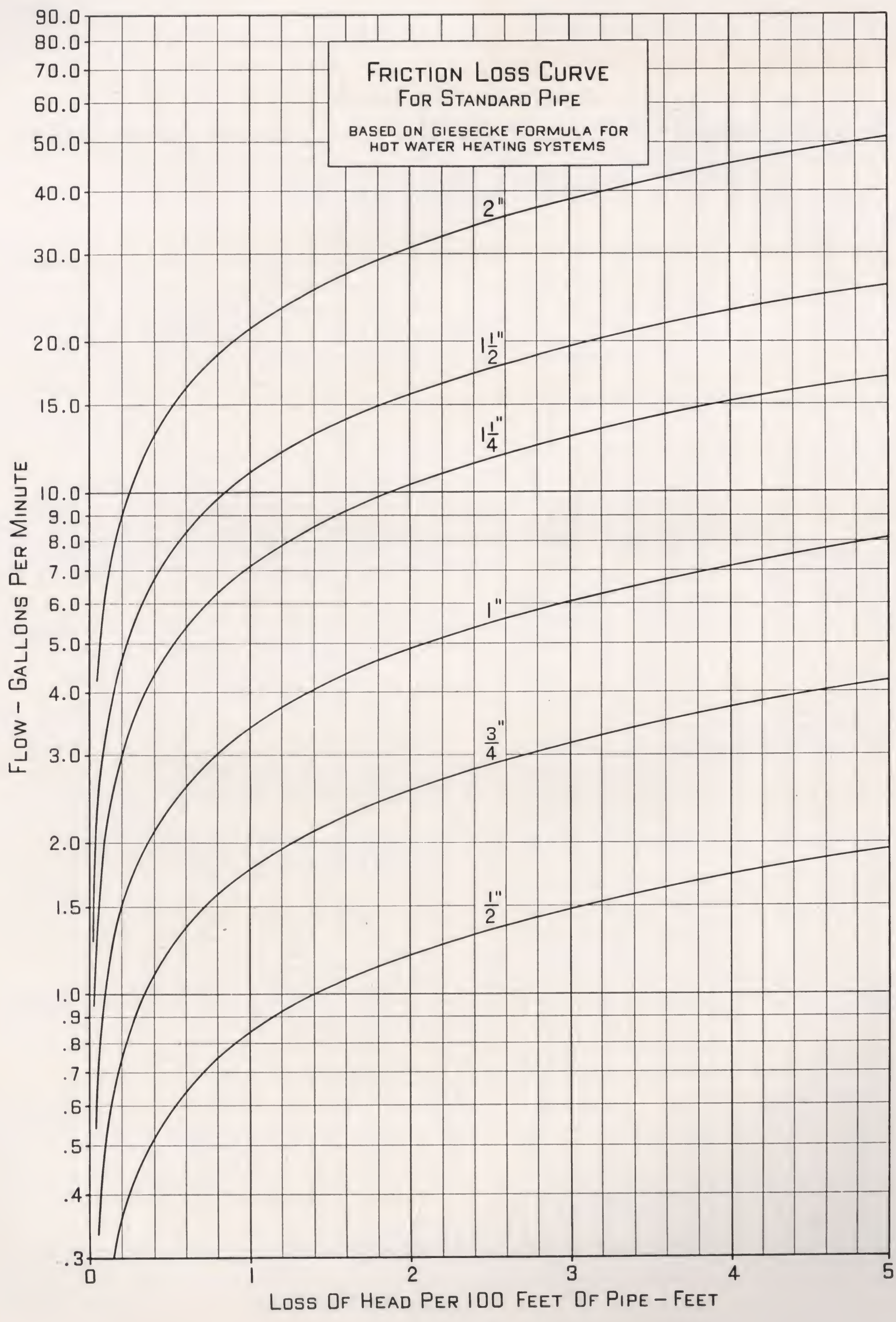
Coefficient *k*

Type	k	Authority
Globe valve	10.0	Crane tests
Angle valve	5.0	Crane tests
Close return bend	2.2	
Standard tee	1.8	Giesecke & Badgett
Standard elbow	.9	Giesecke & Badgett
Medium sweep elbow	.75	Crane tests
Long sweep elbow	.60	Bulletin No. 2712—University of Texas
45° elbow	.42	Bulletin No. 2712—University of Texas
Gate valve (fully open)	.19	Bulletin No. 252—University of Wisconsin
¼ closed	1.15	Bulletin No. 252—University of Wisconsin
½ closed	5.6	Bulletin No. 252—University of Wisconsin
¾ closed	24.0	Bulletin No. 252—University of Wisconsin
Borda entrance	.83	"Hydraulics" Daugherty
Sudden enlargement:		
$d/D = 1/4$	.92	"Hydraulics" Daugherty
$d/D = 1/2$	.56	"Hydraulics" Daugherty
$d/D = 3/4$	.19	"Hydraulics" Daugherty
Ordinary entrance	.50	"Hydraulics" Daugherty
Sudden contraction:		
$d/D = 1/4$	.42	"Hydraulics" Daugherty
$d/D = 1/2$	.33	"Hydraulics" Daugherty
$d/D = 3/4$	.19	"Hydraulics" Daugherty

Courtesy—Crane Co.

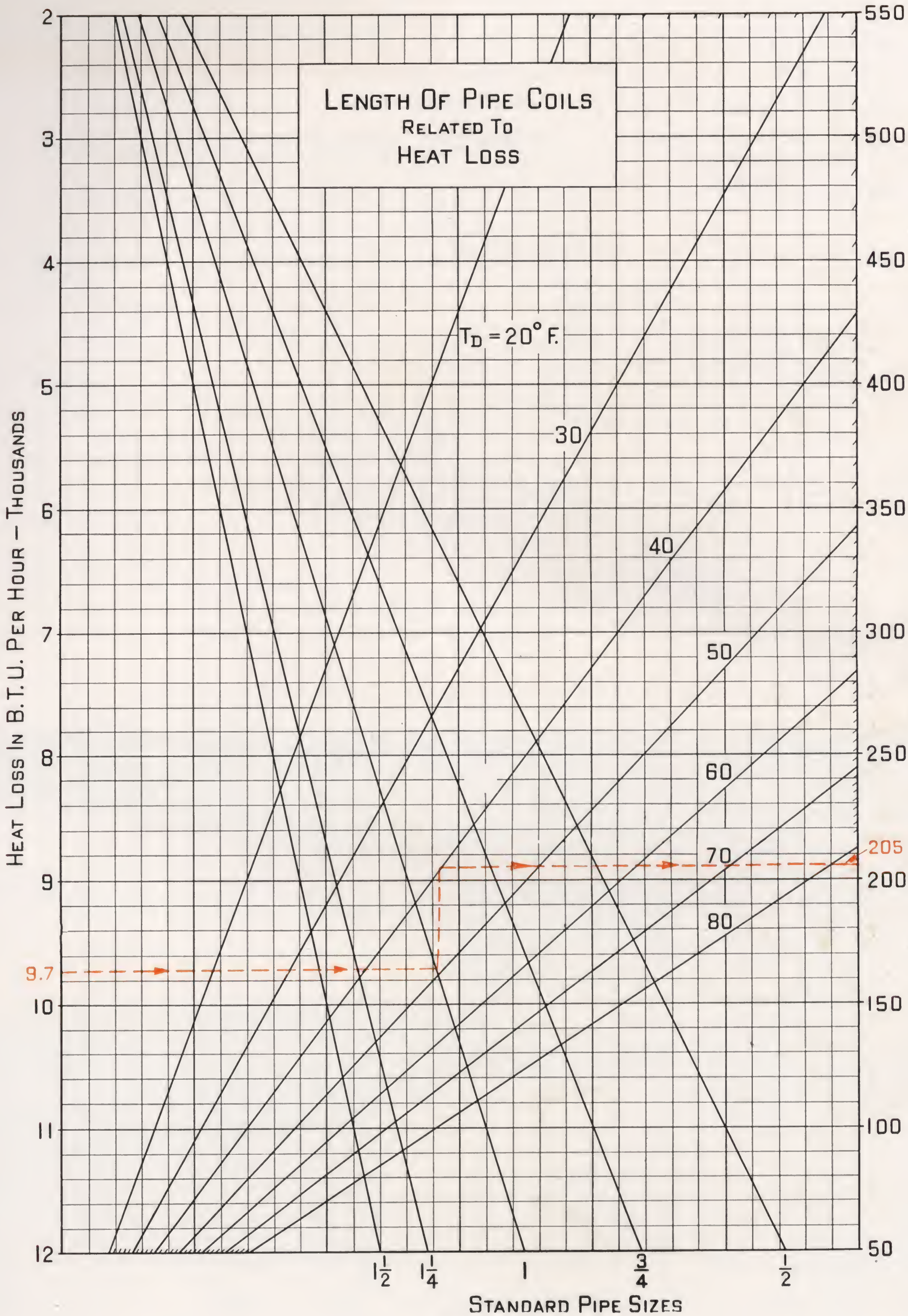
A radiant heating floor panel of NATIONAL Steel Pipe in Country Club Dairy Company's garage, Kansas City, Mo. Coils are shown on building tile before covering with concrete.





FRICTION LOSS CURVE
FOR STANDARD PIPE
BASED ON GIESECKE FORMULA FOR
HOT WATER HEATING SYSTEMS
FLOW – GALLONS PER MINUTE
LOSS OF HEAD PER 100 FEET OF PIPE – FEET
2"
1 1/2"
1 1/4"
1"
3/4"
1/2"
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
15.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.5
1.0
.9
.8
.7
.6
.5
.4
.3
0
1
2
3
4
5

Figure 15



LENGTH OF PIPE COILS
RELATED TO
HEAT LOSS
$T_D = 20°$ F.
30
40
50
60
70
80
HEAT LOSS IN B.T.U. PER HOUR – THOUSANDS
2
3
4
5
6
7
8
9
9.7
10
11
12
LENGTH – FEET OF PIPE
550
500
450
400
350
300
250
205
200
150
100
50
$1\frac{1}{2}$
$1\frac{1}{4}$
1
$\frac{3}{4}$
$\frac{1}{2}$
STANDARD PIPE SIZES

Figure 16

Estimating Heating Coil Requirements†—Ceiling Panel

for Living Room With Wood Floors Over Basement*

(BASED ON THE MRT METHOD)

THERE ARE VARIOUS METHODS of installing pipe coils, and several of these are shown on page 34. In the following example the coils are assumed as installed in the living room ceiling, similar to Figures 1 and 2, page 34, and page 2.

1. Establish the desirable comfort or operative temperature. Radiant Heating Comfort Chart, Figure 18, page 23, shows the operative temperature for houses to be 70° F.

This operative temperature may be obtained by many combinations of the mean radiant temperature (MRT) and air temperature, as the Chart shows. For example, an operative temperature of 70° F. may be obtained with an MRT of 75° F., and an air temperature of 65° F. However, as has been stated previously, the mean radiant and air temperatures will tend to approach equilibrium in houses, offices, and similar structures. For this example 72° F. MRT and 68° F. air are therefore selected.

2. Tabulate the heat loss for a living room of the same dimensions, coefficients, etc., as shown on page 15 but with hardwood floor on yellow pine subflooring on joists (see table below).

3. Establish the surface temperature of the ceiling panel at 100° F.

4. Determine the mean radiant temperature (MRT) for all inside surfaces, excluding the ceiling, as follows:

$$\frac{\text{Transmission coefficient } U \times \text{temperature difference inside room to outside air}}{1.65} = \text{difference between inside surface and operative temperature}$$

or for exposed walls $= \dfrac{0.23 \times 70}{1.65} = 10°$ F.

70° F. − 10° F. = 60° F. inside wall surface temperature

or for windows $= \dfrac{0.45 \times 70}{1.65} = 20°$ F.

70° F. − 20° F. = 50° F. inside window surface temperature

Surfaces of inner walls of room are assumed to be the same as the operative temperature = 70° F.

Surface	Net area square feet	Surface temperature °F.	Net area × surface temperature
Exposed wall	155	60	9300
Exposed wall	87.25	60	5235
Inside wall	176	70	12320
Inside wall	96	70	6720
Windows	29.75	50	1487
Floor	264	70	18480
Totals	808		53542

53542 ÷ 808 = 66° F. MRT of inside surfaces excluding ceiling. The temperature of the ceiling outside the panel area does not affect this MRT value for estimating purposes.

5. Determine the heat delivered by radiation for a panel temperature of 100° F., and an MRT of 66° F. From Chart, Figure 19, this is equal to 34 B.T.U.'s per hour per square foot of panel surface.

6. Determine the heat delivered by convection for 100° F. panel surface and 68° F. air temperature. The difference in temperature is 100° F. − 68° F. = 32° F. From Chart, Figure 20, the rate of heat delivered by convection is 0.52 B.T.U. per square foot per hour per degree F. or 0.52×32° = 16.6

	Dimensions feet	Net area square feet	Transmission coefficient U	Temperature difference °F.	Heat loss B.T.U.'s/hr.
Exposed wall	‡ 8×22	155	.23	70	2496
Exposed wall	‡ 8×12	87.25	.23	70	1405
Window	3.5×6	21	.45	70	662
Window	2.5×3.5	8.75	.45	70	276
*Floor	12×22	264	.34	5	449
Air change	Total vol. = 2112 cu. ft. × .018 × 70° F.				2661
			Total heat loss		7949 B.T.U.'s/hr.

†Based on data from "Radiant Heating and Cooling" by F. E. Giesecke, Consulting Engineer, and published in "Heating, Piping and Air Conditioning," June to October, 1940.

*The basement beneath living room is a heated game room. Recommended operative temperature 65° F. Source of heat loss coefficients for window and ceiling given in Table, page 15.

‡Excluding windows.

B.T.U.'s per hour per square foot of panel surface.

7. Add (5) and (6) or $34+16.6=50.6$ B.T.U.'s per hour of radiated and convected heat per square foot of panel surface.

8. Determine panel area required.

$$\frac{\text{Total heat loss}}{\text{Heat transfer rate}}=\frac{7949}{50.6}=157 \text{ square feet.}$$

A panel** 16 feet long by 10 feet wide meets this area requirement.

9. Assume a pipe size and spacing for coils, say 1-inch standard pipe on 12-inch (1-foot) centers. See Figure 17.

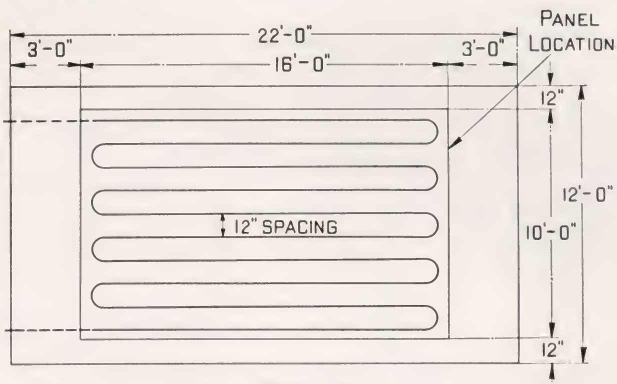


Figure 17

10. Find the length of pipe required for the panel by dividing the area (8) by the spacing selected in feet (9).

$$\frac{\text{Area}}{\text{Spacing}}=\frac{16\times 10}{1}=160 \text{ feet}$$

11. Assume that the insulation above the panel is such that 10 per cent of the heat delivered flows upward and 90 per cent downward. Divide the total heat loss (2) by 0.90.

$\frac{7949}{0.90}=8830$ B.T.U.'s per hour to be delivered by panel.

12. Divide the heat to be delivered by the panel by the length of coil:

$$\frac{8830}{160}=55 \text{ B.T.U.'s per linear foot of pipe}$$

13. Divide the total heat transfer rate per linear foot of pipe (12) by the tabulated heat transfer rate per foot (page 16) for 1-inch pipe to obtain the difference between room air and required water temperature.

**Some design engineers utilize the full ceiling areas as a heating panel.

$\frac{55}{1.2}=46°$ F. temperature difference, water to air.

The average water temperature required in the coils to deliver the required heat should thus be equal to room air temperature plus temperature difference, water to room air:

$$68° + 46.8° = 114.8° \text{ F.}$$

14. Determine the MRT of all room surfaces and check against required design MRT of 72° F.

$$\frac{(\text{Panel area}\times\text{panel temperature})+(\text{Total area all surfaces}-\text{panel area}\times\text{MRT of step 4})}{\text{Total area all surfaces}}=$$

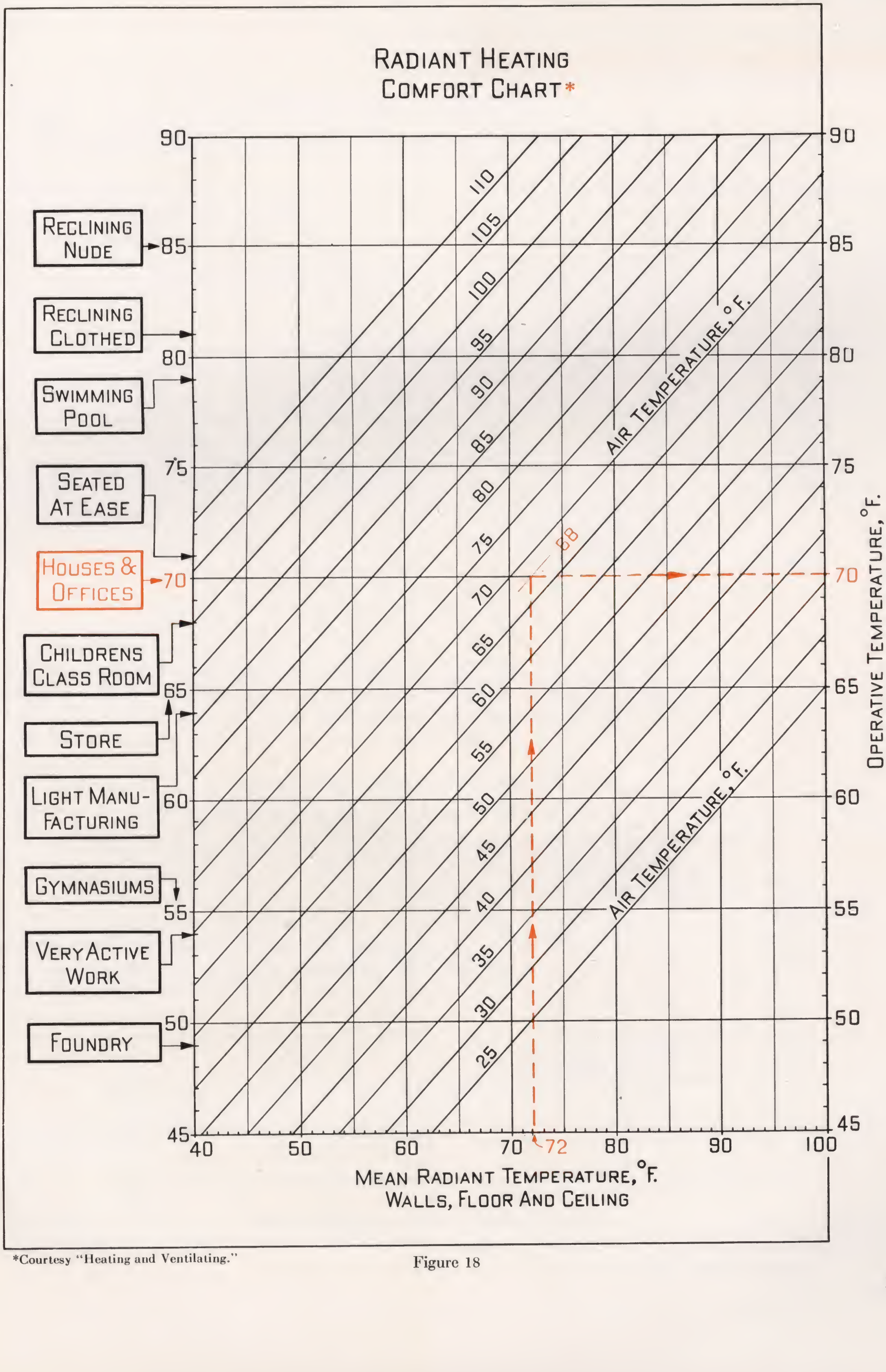
$$\frac{(160\times 100° \text{ F.})+(912\times 66° \text{ F.})}{1072}=\frac{76192}{1072}=71.1° \text{ F.}$$

MRT which is satisfactory.

By use of emissivity coefficients for surfaces radiating to absolute zero, a more accurate analysis gives 72.2° F. for a final MRT. Should 72° F. MRT and 68° F. air not produce satisfactory conditions, the ceiling temperature can easily be adjusted as required by changing the temperature of the circulating water.

15. The method of determining water flow capacity and friction loss is outlined on pages 16 and 17.

Ceiling coils in the first floor rooms of a modern residence.



*Courtesy "Heating and Ventilating."

Figure 18

HEAT DELIVERED BY RADIATION
TO ROOM BY PANEL*

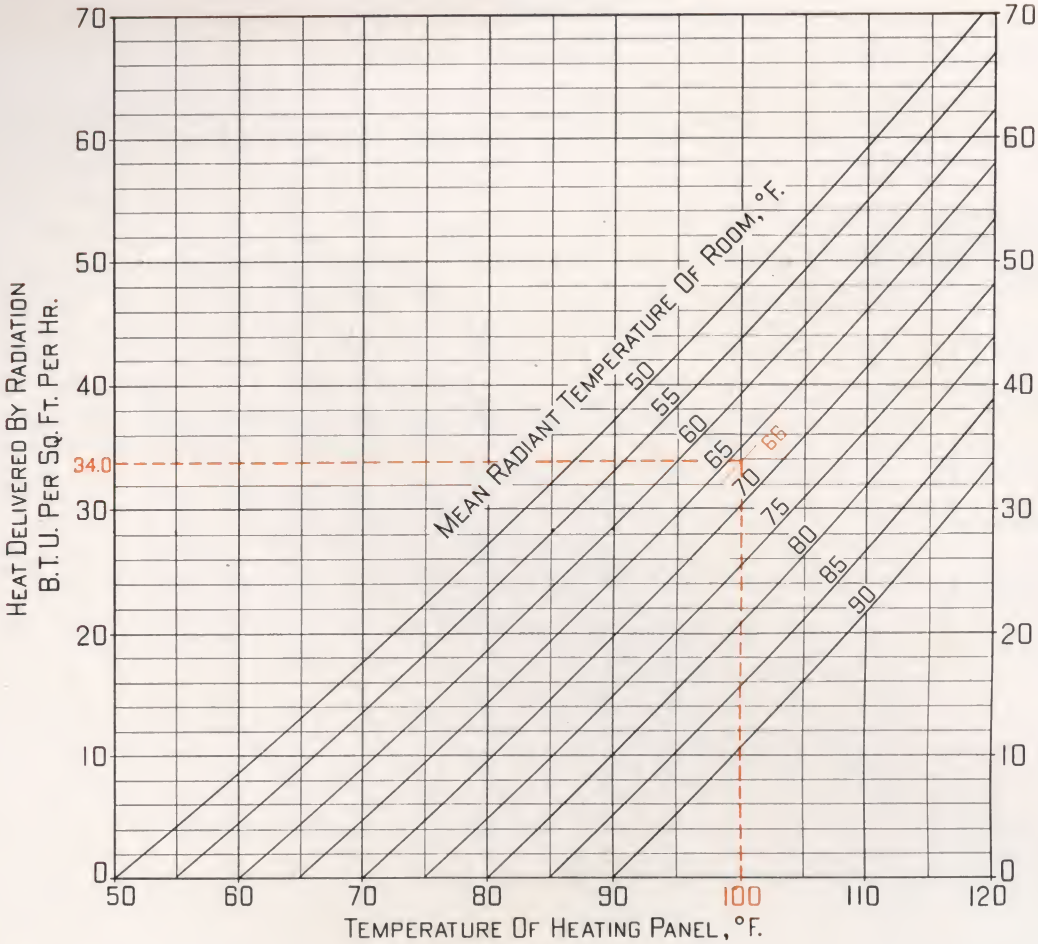


Figure 19

HEAT TRANSMISSION FROM PANEL TO AIR
BY CONVECTION AND CONDUCTION*

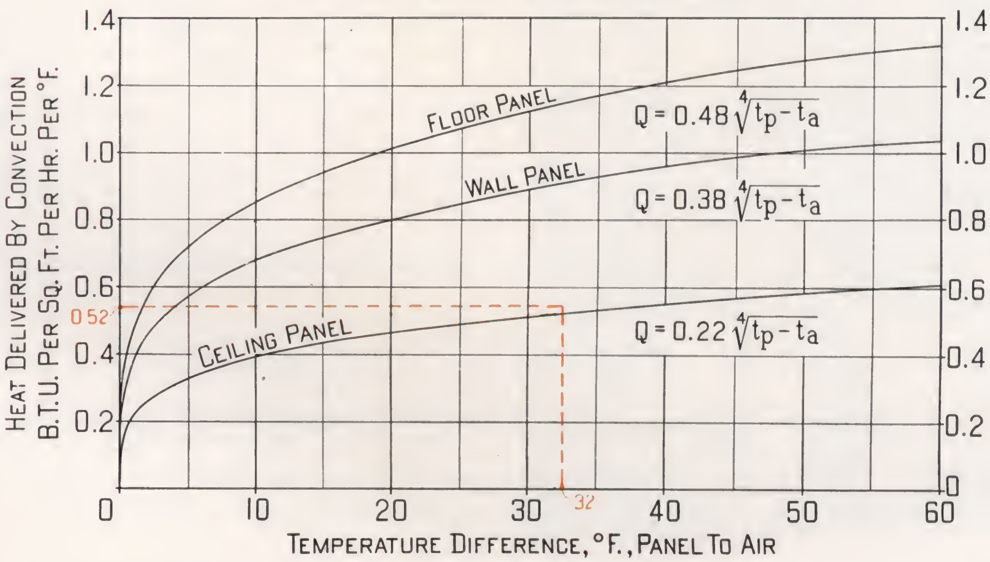


Figure 20

*Courtesy "Heating, Piping and Air Conditioning" and F. E. Giesecke, Consulting Engineer.

Heat Losses Through Floors of Basementless Buildings†

THERE HAS LONG BEEN SOME QUESTION regarding the accuracy of estimates of heat loss through the floors of basementless buildings. Heat loss coefficients in standard tables are for air-to-air; in the case of floors laid on the ground the air-to-air coefficient is probably in error. In addition, the temperature of the ground below the floor is exceedingly difficult to estimate.

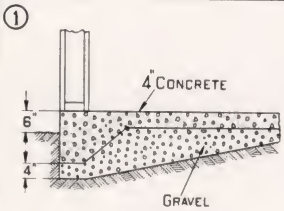
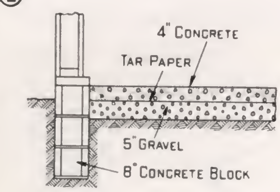
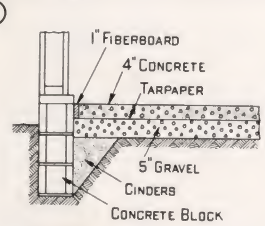
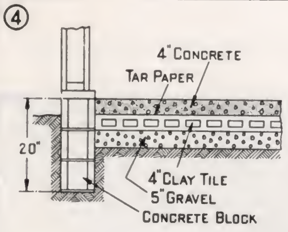
Nevertheless, the estimating problem exists, especially in the field of low cost housing, and has recently received attention by the National Bureau of Standards, whose findings have been reported in one of the Department of Commerce Building Materials and Structures booklets.* The study was of concrete floors and wood floors laid over crawl spaces as well as on the ground.

The results showed that the heat loss of the floors laid on the ground was decreased by insulating the edges; that the heat loss through the center of such floors is relatively small when the enclosing structure is continuously heated; that the edge loss for a wood floor laid over a crawl space is small; and that the edge loss for an insulated concrete floor laid over a crawl space was considerable. The floors tested are illustrated in types 1 to 8 in the accompanying drawings and on page 27.

For determining the heat loss through these floors, the general plan adopted was to provide a heavily insulated structure above a specimen of each kind of floor and to observe the amount of heat, supplied in the form of electric energy, necessary to maintain a temperature of 70° F. within the structure during cold weather. Although the walls and ceiling of the structure were heavily insulated, some heat loss through them was inevitable. To correct the data for this condition, tests were made during which the floors themselves were so insulated that the heat loss through the structure could be measured.

FLOORS ON GROUND

The investigators concluded that the heat loss of a floor laid on the ground is not proportional to the temperature difference between the air inside and the air outside of the house at any given instant. The floor heat loss appears to be dependent upon the temperature of the ground at some region beneath the surface, and this, in turn, depends upon the average temperature of the air above the ground and the amount of heat received by the ground from the sun and the amount of heat loss from it by radiation or otherwise during some period prior to the observation.

Type Of Floor	Value Of "F" In B.T.U. Per Hour Per Foot Of Edge Per Degree F.
① 	0.81
② 	0.69
③ 	0.55
④ 	0.75

Four types of floor laid on ground. Loss factor "F" takes into account the exposed edge.

For each of the floors, 1, 2, 3, and 4, the observed heat loss was divided by the length of the exposed

†From "Heating and Ventilating," by courtesy of the publisher.
*Report, BMS103, "Measurement of Heat Losses from Slab Floors," by Richard S. Dill, W. C. Robinson, and H. E. Robinson. Available from the Superintendent of Documents, 10 cents.

edge, as defined on page 25, and the result entered in the tables as "heat loss per foot of exposed edge." From this, three factors were derived, one of which is particularly useful.

The heat loss in B.T.U.'s per hour per linear foot of exposed edge was divided by the average temperature difference observed during each observation period between the air inside the structure and the air outside, to yield a factor "F" which takes into account the exposed edge.

For estimating design heat losses from slab floors on the ground, the investigators propose three formulas, of which the following is suggested by them as probably being the most adaptable:

$$Q = LF\ (T_i - T_g)$$

where

Q = heat loss through floor, B.T.U.'s per hour,
L = length of floor edge adjacent to exposed wall of building, feet,
F = heat loss factor, B.T.U.'s per degree temperature difference,
T_i = inside design temperature, F,
T_g = average outside temperature for week preceding instant for which estimate is to be made, F.

The last term (T_g) is the only one for which data are not readily available. The report did not include a table of this factor for various localities and, unfortunately, as defined, the data could be confusing. To simplify the matter and to be on the safe side, it seems that T_g could be defined as

T_g = average outside temperature for the week preceding the coldest temperature of record, F.

Such data are simple to compile and have been obtained by questionnaire; see Table 1.

The following example will indicate the application of the equation.

EXAMPLE

A 30 × 28-foot residence near New York City is built on a slab of 4 inches of concrete laid on 5 inches of gravel. What will be the floor heat loss?

TABLE 1

VALUES OF T_g FOR 51 CITIES FOR ESTIMATING HEAT LOSSES THROUGH FLOORS OF BASEMENTLESS BUILDINGS

Albany, N. Y.	5	Houston, Tex.	43	Portland, Me.	12
Atlanta, Ga.	20	Indianapolis, Ind.	16	Portland, Ore.	20
Baltimore, Md.	21	Kansas City, Mo.	−2	Rochester, N. Y.	6
Birmingham, Ala.	19	Lincoln, Neb.	0	St. Louis, Mo.	15
Boston, Mass.	8	Little Rock, Ark.	13	Salt Lake City, Utah	9
Buffalo, N. Y.	6	Los Angeles, Calif.	51	San Diego, Calif.	49
Chicago, Ill.	5	Louisville, Ky.	25	San Francisco, Calif.	45
Cincinnati, Ohio	17	Memphis, Tenn.	12	Savannah, Ga.	38
Cleveland, Ohio	16	Milwaukee, Wisc.	1	Scranton, Pa.	8
Dallas, Tex.	26	Minneapolis, Minn.	−4	Seattle, Wash.	29
Denver, Colo.	8	Nashville, Tenn.	14	Spokane, Wash.	−1
Detroit, Mich.	14	New Haven, Conn.	9	Syracuse, N. Y.	9
Duluth, Minn.	5	New Orleans, La.	32	Topeka, Kansas	−2
Fort Wayne, Ind.	13	New York, N. Y.	14	Trenton, N. J.	12
Grand Rapids, Mich.	8	Oklahoma City, Okla.	9	Utica, N. Y.	4
Harrisburg, Pa.	9	Philadelphia, Pa.	18	Washington, D. C.	14
Hartford, Conn.	16	Pittsburgh, Pa.	12	Wichita, Kansas	0

The Vivian Webb Chapel at the Webb School of Claremont, California, radiant heated with NATIONAL Steel Pipe.

A floor panel of 1½-inch NATIONAL Steel Pipe for the Vivian Webb Chapel.

SOLUTION

The slab is similar to floor type 2, for which $F = 0.69$. The exposed edge L will add up to $(30+30+28+28) = 116$ feet. Presumably the inside temperature would be 70° F., and from the table, T_g for New York = 14° F., so that

$Q = 116 \times 0.69\ (70-14) = 4480$ B.T.U.'s per hour.

The data are probably sufficiently accurate basis for most estimating purposes because the floor heat loss is likely to be small compared to other losses. However, the data are incomplete in that they do not cover the cases of frozen ground and of snow-blanketed ground. To supply data, it would be necessary to repeat the tests in a colder climate.

No reason is apparent why the data are not applicable for regions where the average outdoor temperature does not remain continuously below freezing for more than a day or so, except that snow, which is an insulator, may decrease floor heat loss.

The data indicate that insulating the floor at the edge is beneficial both in saving heat and in reducing lateral temperature gradients across the floor.

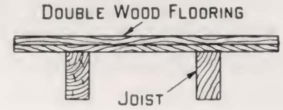
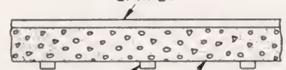
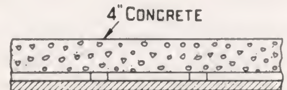
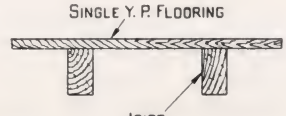
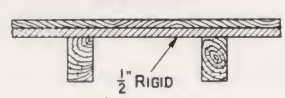
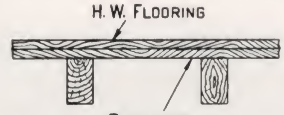
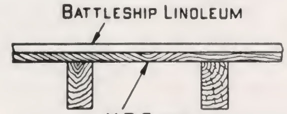
FLOORS OVER CRAWL SPACE

Floors tested by the Bureau over crawl spaces are illustrated in types 5 to 8, inclusive. This type of floor has a conventional heat loss coefficient (air-to-air). The authors' results checked computed values of U as follows:

Floor Type	U Value	
	Observed	Computed
5	0.24	0.27
6	0.46	0.50
7	0.34	0.38
8	0.30	0.17

Summing up, the tests on floors laid over crawl spaces indicated that the factors contained in handbooks are suitable for estimating heat losses through such floors, except in the case of a floor which is heavily insulated on the underside. In this case, the edge loss increases largely in comparison to the total loss through the floor, and this may result in an underestimate unless it is taken into consideration. The number of factors involved indicate that heat losses through floors laid over crawl spaces should be computed on the basis of an estimated crawl-space temperature. For a continuously ventilated crawl space, the temperature should be assumed to be the same as the outdoor temperature.

Since the usual U values were found to be reasonably accurate for floors over crawl spaces, the accompanying table gives U values for four other floors (9 to 12, inclusive) *not tested* by the Bureau. These values are from H & V's Reference Data 73-74, and are included for convenience.

Type Of Floor	Value Of "U" In B.T.U. Per Hour Per Foot Of Edge Per Degree F.
(5)  Double Wood Flooring; Joist	0.24
(6)  4" Concrete; 1" Nailing Strips	0.46
(7)  Carpet; 1" Nailing Strips; 4" Concrete	0.34
(8)  4" Concrete; 1" Fiberboard	0.30
(9)  Single Y. P. Flooring; Joist	0.45
(10)  Single Floor; ½" Rigid Insulation	0.27
(11)  H. W. Flooring; Subfloor	0.34
(12)  Battleship Linoleum; Y. P. Floor	0.34

Floors over crawl spaces. Conventional loss coefficient U is used.

What Heating Engineers Claim for Radiant Heating

1. ECONOMY OF OPERATION

With good controls, savings in operating costs of as much as 30 per cent and higher are reported for radiant heating systems over the conventional heating systems.

2. EVEN DISTRIBUTION OF HEAT

Heating coils are designed so that they effectively transfer heat through the entire ceiling or floor surface, resulting in low, yet adequate, floor and ceiling surface temperatures and in a more uniform distribution of heat in the room.

3. GREATER WALL SURFACE AVAILABLE

There are no visible parts in a radiant heating system, heating coils being buried beneath the floor, or in the space between ceiling and the floor above. Greater wall space is thus available for placing of furniture and for decorative effects.

4. INCREASED FEELING OF COMFORT

The air in a room heated by radiation does not dry out as does air passing through or in contact with a high temperature heating unit. It is fresh, moderate in temperature, and gives the room occupant a more alert feeling. There is complete lack of stuffiness, as commonly found in overheated air.

5. CLEANLINESS

Because there are no air currents set up, dust is not carried and deposited on room surfaces, furniture, and draperies.

6. FLOOR UTILITY

The temperature of floors in radiant heating systems are in the temperature range of 75° Fahrenheit to 85° Fahrenheit and the health of children using floors to play on is thus safeguarded.

7. BETTER ROOM TEMPERATURE CONTROL

There are no drafts or hot and cold spots in a room heated by a radiant system. Because of the uniform distribution of heat from the entire floor or ceiling surface, the temperature is practically uniform at all levels and in all parts of the room.

8. AUTOMATICALLY CONTROLLED

A radiant heating system is automatically controlled by thermostat, and, once in operation, requires little or no attention.

9. NOISELESS IN OPERATION

Because the only moving parts in a radiant heating system are contained in the circulating pump, the system is noiseless and the room occupant is unaware of its operation.

10. PSYCHOLOGICAL EFFECT

The application of heat from the floor seems to produce a psychological relaxation on the part of workmen assembling equipment, particularly equipment which includes the handling of small parts requiring a good deal of concentration. This more restful and comfortable feeling develops a better mental attitude which reduces the amount of errors and increases the quality of the work.

Heiland Research Corporation, Denver, Colorado, used 6000 feet of 1-inch NATIONAL Steel Pipe for radiant heating.

Radiant Heating Question Box*

Q. 1. *What size pipe should be used for a radiant heating job?*

A. Pipe coils for radiant heating are generally constructed with ½, ¾, 1, or 1¼-inch pipe.

In selecting a particular pipe size for a radiant heating job, the designer is governed by a proper balance between the cost of such a system and efficiency in operation. He must consider the required heat transfer from the panel to the room or space to be heated, and this depends upon the heat lost through the walls, windows, and other surfaces of the building. Generally speaking, he must decide which pipe size at stated center to center distance will give the desired heat transfer from the radiant heating coils to the space to be heated at the lowest cost per foot of pipe or per coil.

The Heating, Ventilating and Air Conditioning Guide 1945 states that, when hot water pipes are embedded in concrete slabs or attached to plastered surfaces, their rate of heat emission may be assumed as:

> 0.8 B.T.U. per hour per linear foot for ½-inch pipe when spaced on 6-inch centers
>
> 1.0 B.T.U. per hour per linear foot for ¾-inch pipe when spaced on 9-inch centers
>
> 1.2 B.T.U. per hour per linear foot for 1-inch pipe when spaced on 12-inch centers

for each degree difference in temperature between coil water temperature and air temperature.

This information is given as a general guide for the designer, and the values will vary depending on depth of pipe below surface of panel, and on materials from which panel is constructed. Additional experience and research will develop more definite and complete data. Actual installation tests show these values to be very conservative.

Another factor in determining pipe size is the quantity of hot water which must be distributed through the coils. We may obtain the necessary heat transfer from coils to room with a certain pipe size and spacing, but we must also determine whether or not the friction loss developed in distributing the necessary quantity of water is excessive, for this influences the pump size.

Q. 2. *What is the approximate cost of a radiant heating system?*

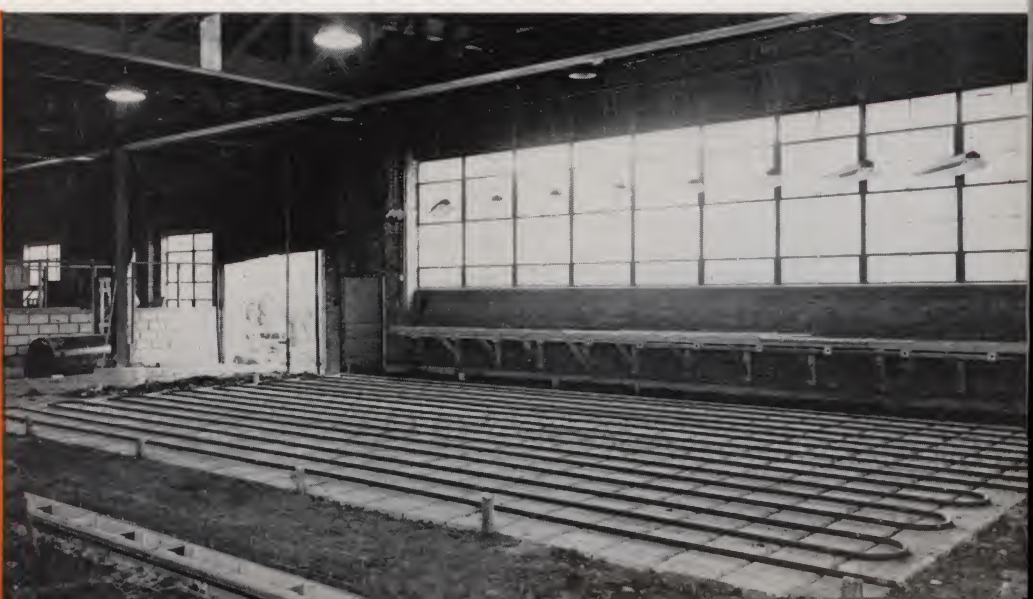
A. Mr. Raymond Viner Hall, prominent architect, gives the following as the cost of several radiant heating installations and the percentage of the total cost of the home in each case:

Job	Total cost	Radiant heating	Per cent	Fuel
A	$5,200	$495	9.5	Gas
B	5,200	375	7.2	Coal
C	6,500	525	8.1	Gas
D	7,000	675	9.6	Oil
E	8,500	575	6.8	Gas

After reviewing the cost of twenty radiant heating jobs installed during 1940 and 1941, Mr. Hall states "Even those whose mania is operational costs need not apologize for the first cost of the floor type heating system."

*Based on inquiries received by National Tube Company.

Radiant heating floor panel of NATIONAL Steel Pipe in Country Club Dairy Company's garage in Kansas City, Mo. Pipe laid on building tile preparatory to covering with concrete.



The cost of a complete system varied in the year 1941 from 72 dollars to 136 dollars per room, excluding baths and attached garages, and depending on the type of fuel, controls, etc.

These systems have represented from 6.8 per cent to 9.6 per cent of the total construction cost.

Q. 3. *Would a radiant heating job cost more than a hot air job?*

A. A radiant heating installation might cost more than a hot air gravity heating system but could easily cost less than a system equipped with blowers, but this higher cost is offset by less fuel consumption and better comfort conditions for the occupants of the building.

There are no hot and cold air grilles to take up space and mar the appearance of walls, or to cut down on available wall or floor space for placing of furniture. Where grilles are placed at baseboard level the entire wall space above may be useless in placing furniture, and in the case of expensive pieces like pianos and radios, the forced hot air entering a room influences their location.

The cost of installation of radiant heat to the prospective user is not to be measured only in terms of dollars and cents.

Q. 4. *Would it cost more or less to operate a radiant heating system than other types, and by how much?*

A. Experience has shown that a well-designed and installed radiant heating system is much more economical to operate than other systems.

Savings of 30 per cent and higher over operating costs of other systems are recorded, where good controls are used.

Q. 5. *Would a radiant heating installation have to be a welded job?*

A. Either threaded and coupled joints or welded joints may be used in fabricating coils; however, welded joints are used almost exclusively and are the preferred method. In either case the system should be subject to a hydrostatic test pressure of not less than 5 times the intended operating pressure.

Q. 6. *In a building without any basement how would the pipe be laid?*

A. The coils would, if designed for a floor installation, be placed in the floor structure approximately as illustrated on page 34.

If concrete is used general practice is to set the fabricated coils on a gravel base which has been first covered with a layer of about one inch of sand. The concrete is then poured over the coils. Various modifications of this method are in use, some of which require placing of insulation beneath the coils, and others embedding the coils in the concrete rather than laying on sand over gravel. All of these modifications have as their primary purpose, obtaining greater transfer of heat from the coils upward into the space to be heated, and corresponding reduction of heat loss to the ground.

Q. 7. *In a building having a basement, what would be the procedure for installation?*

A. Assuming that the basement is to be used frequently by the occupants, and is to contain a game room or workshop, it would be desirable to design for a floor panel. In existing buildings, wall coils may be used in the basement. The space above the basement may be heated by coils installed in the floor or ceiling above. Where pipe is to be so installed, it should be run above the joists for the floor or under the joists if installed in the ceiling. In either case, the pipe should be securely attached to the joists.

Q. 8. *Would much heat be lost to the ground through the concrete slab?*

A. In a concrete slab heating panel there is initial heat loss to the ground when the unit is first placed in operation. This however occurs mainly during the warming up period, and as the soil becomes warm, less and less heat is lost until when the system is in full operation heat loss to the ground is a small percentage, provided a good layer of broken stone or other insulating material is placed below the concrete floor.

Q. 9. *Is much heat transmitted to the basement from coils in the floor above?*

A. The heat transmitted to the basement from coils built into the floor of the surface above would depend upon the method of installation and particularly on insulating value of materials beneath the coils. The heat transfer to the basement depends also upon the temperature differential between the basement and that of the room above. Since the basement temperature will generally be lower than that of the room above, an allowance should be made for the loss from the rooms above through the floor, and in the usual manner based on the "heat loss coefficients" for the materials used in the floor.

Q. 10. *How does the heat transfer property of wrought steel pipe in radiant heating systems compare with that of wrought iron or copper pipe?*

A. For all practical purposes they are the same. When coils are set on sand or gravel and a concrete slab poured over them, or where they are embedded

in plaster, the transfer of heat from the pipe to the concrete or plaster surface is by conduction.

A noted authority on radiant heating states that "when so installed there is practically no difference in the B.T.U. transfer rate from the concrete or plaster surface, for wrought steel, wrought iron, or copper pipe."

Q. 11. ***How does the coefficient of expansion of wrought steel pipe compare with that of wrought iron pipe?***

A. The mean coefficient of linear expansion for wrought steel pipe in the temperature range of 32° F. to 392° F. is equal to 0.0000068 compared with 0.0000072 for wrought iron. Therefore, if a radiant heating coil whose overall length is 40 feet is installed at 40° F. and after the concrete is poured and set, heated by the passage of water to 140° F., it will, if constructed of iron pipe, expand 0.32 inches as compared with 0.31 inches for steel pipe. The coefficient of linear expansion of concrete depends to some extent on the concrete mix. For a 1: 1½: 3 concrete mix, the coefficient generally used is the same as that for steel or 0.0000068. In other words, for practical purposes these coefficients are the same.

Q. 12. ***Is corrosion a factor in radiant heating systems?***

A. Corrosion is an inconsequential factor in a radiant heating system correctly designed, and can be disregarded in selection of piping materials. Radiant heating systems differ basically from present conventional heating systems in only one important respect, namely, "the method of heat transfer." Both systems use the same heating medium—hot water or steam; both are assembled from the same equipment—boiler, piping, and controls; both depend on the same fuels—gas, coal, or oil. In other words, the character of service performed, particularly with respect to the piping, is identical. Both are closed circuits. Once in operation, the same water is recirculated over and over again. It is a matter of common knowledge that the small amount of dissolved oxygen entering a system when first filled, and in the occasional make-up, is quickly absorbed and of inconsequential effect on the piping and boiler in any closed circuit. Since corrosion does not take place unless there is a continuous supply of oxygen, it is obvious that this factor is of no consequence whatever in radiant systems, regardless of the kind of pipe used. Throughout the country and over a long period of years in hundreds of thousands, even millions, of buildings of all types, including homes, office buildings, schools, and public buildings, etc. conventional closed circuit hot water systems have been used with a remarkable record of freedom from trouble caused by corrosion. During this period numerous buildings torn down or remodeled revealed that the piping removed from the heating system, including both steel and iron, was in a good state of preservation and outlasted the serviceable life of the building by a wide margin. Therefore, since the functional service of pipe in a radiant system is identical with that of a regular pipe and radiator system, the factor of corrosion can be regarded as an item of no consequence. Since the introduction of radiant systems in this country, various kinds of pipe have been employed, but the predominant tonnage has been of wrought steel and

E. C. Hall Company Building at Tigard, Oregon, radiant heated with NATIONAL Steel Pipe.

wrought iron. Both of these materials have served with equal satisfaction and substantiate the previous records developed through many actual service tests and investigations of the relative behavior of steel and iron in hot water service.

Similarly with respect to external corrosion, when pipe is buried in concrete slabs, external corrosion is not of any greater consequence than in using steel reinforcing bars.

When installed in wood construction floors or ceilings, the temperature of the pipe coils being higher than that of the surrounding air, condensation is not a factor and corrosion does not occur.

Q. 13. ***How do the bending properties of wrought steel pipe compare with those of wrought iron pipe?***

A. All tables which list the shortest radius to which pipe may be bent, indicate a shorter permissible radius for wrought steel pipe than for wrought iron pipe. However, both steel and iron pipe may be bent to the radii generally required in radiant heating coils without affecting the strength of the pipe material adversely.

Q. 14. ***Having a broadloom carpet laid wall to wall over a standard type rug pad, all directly on the concrete heating slab, what would be the effect on the heat transfer?***

A. Mr. Elmo Hall, prominent heating engineer, has investigated this matter and his findings are as follows:

"This question seems to worry many engineers who know that rugs, furniture, files, and other equipment will be placed on or adjacent to their floor heating panels. Imagine, then, the author's surprise to find the entire floor space of a hangar heated by floor panels covered for several months with insulating wooden floor panels designed as a base for buildings used in arctic operations. These wooden panels, 4′×8′ in size, consist of a 2×4 frame covered with ⅞″ matched flooring on one side, ½″ laminated panels on the other with the space between the 2×4 joists packed with loose insulating material. In the hangar in question, the concrete floor is 4 inches high in the center of the hangar and the wooden panels touched the concrete only at that point being wedged up toward the outside walls to bring them level, thus providing another insulating air space.

Floor panel coils for second floor bathroom of residence in Denver.

"It seems impossible to devise a more severe insulating test for a radiant floor panel, yet the thermostats located above the insulating panels showed the same temperature as before the insulating panels were placed on the floor with a rise in concrete temperature from 72° F. to 86° F. and with the *top* of the insulated panels the same temperature as the floor had been previously. The panels were in place two months before the author found them and, while there must have been a time lag in again bringing the building up to design temperature, several of the personnel working in the space who were questioned could shed no light on the lag and stated that if such lag occurred, they had not been aware of it. Since witnessing this accidental test, the author will never again worry over a few rugs or pictures placed on or in front of a heating panel."

Q. 15. ***How is aluminum foil used to prevent heat loss?***

A. Regarding the use of aluminum for insulating purposes, the following is quoted from a report of the U. S. Bureau of Standards Letter Circular LC535:

"Since the principles involved in the use of aluminum foil or other bright metal sheet as thermal insulation are not generally understood, a brief discussion will be given here. Aluminum foil is used to increase the insulating value of air spaces by reducing heat transfer by radiation. It is of value only in conjunction with air spaces, and has no value when placed in continuous contact with solid

material on both sides, except in so far as it may act as a building paper in preventing air leakage.

"Clean metallic surfaces in general are good reflectors and poor emitters of radiant heat. Since a large proportion of the heat transfer across air spaces bounded by non-metallic materials takes place by radiation, the use of aluminum as one or both boundaries of a space will materially reduce the heat transfer across the space. It will be evident that the insulating effect does not depend on the thickness of the metallic foil, while the insulating value of ordinary types of insulating materials depends mainly on their thickness. The insulating value of air spaces bounded on one or both interior surfaces with aluminum foil increases with increasing width of space up to about ¾-inch width. Spaces wider than about ¾ inch have substantially the same insulating value, regardless of width.

"While there is limited information as to the permanence of the reflective surfaces of aluminum under various conditions of use, such information as is available indicates that under normal conditions the reflectivity is likely to be reasonably permanent. Installations are reported where no appreciable deterioration of the aluminum has occurred over a considerable period of years. Thin layers of dust readily visible to the eye do not cause any very serious lowering in the reflecting power. If aluminum is wetted over considerable periods of time, there is possibility of corrosion, particularly if the water is alkaline. The appearance of the surface is not a reliable guide as to its reflectivity for radiant heat, and foil which appears dark or discolored may have lost little in insulating value if the surface film is thin.

"The use of lacquer to resist possible corrosion under severe conditions of use reduces the reflecting power to some extent. The effect of a very thin coat of lacquer is small, but relatively thick lacquers, even though they are almost invisible to the eye, may seriously reduce the effectiveness of the foil.

"The effect of reduced reflectivity on heat transfer across an air space is less marked the narrower the space, since heat transfer by conduction and convection plays a more important role than radiation in the case of narrow air spaces.

"Aluminum foil is also applied in a crumpled form so that it is self-spacing. If two or three crumpled sheets are hung in the air space of a frame wall, there is so little contact between the sheets that the insulating values are essentially the same as those given for the spaced sheets."

Q. 16. ***Are floors of radiant heated rooms uncomfortably warm?***

A. No. The surface temperature of a properly designed floor type radiant heating installation is between 75 and 85 degrees, and experience has shown that when designed for this range of temperatures, comfortable conditions are found to exist.

The Heating, Ventilating and Air Conditioning Guide 1945 lists the following as desirable heating surface temperatures:

Highest Safe Surface Temperatures for Heating Panels

Type of panel	Surface temperature degree F.
Plastered Ceiling (Pipe embedded)	115
Plastered Walls (Pipe embedded)	120
Floor, any method	90
Floor, Border, and Aisles	120

Low surface temperature radiation is recommended regardless of the heating medium employed.

Floor panel installation for the Perfection Pipe Nipple Company plant at Madison, Ohio. Three thousand feet of 1¼-inch NATIONAL Steel Pipe were used for these coils.

Methods of Floor and Ceiling Installation of Radiant Heating Coils

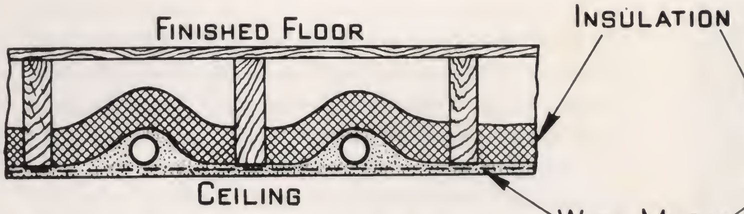


Figure 1. The radiant heating coil is laid on lath which is attached to the joists in the usual manner. Rock wool or any other loose insulating material is then laid over the pipe between joists.

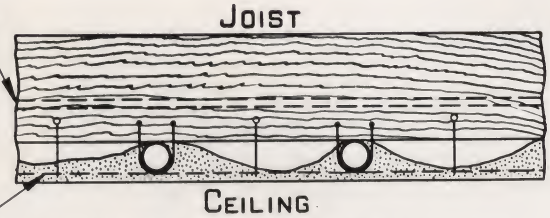


Figure 2. The coil is hung below the joists with the metal mesh lathing wired to the pipe. Plaster is then applied to the lath and covers the pipe as indicated.

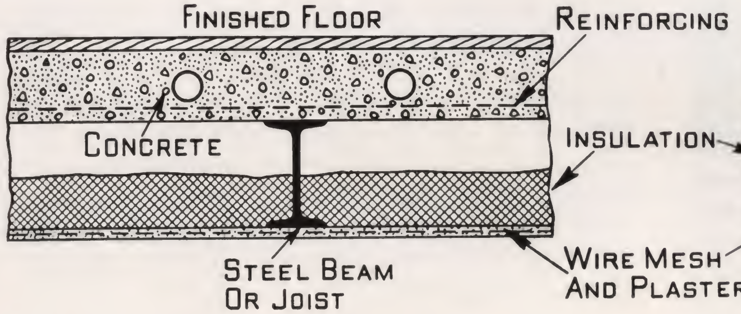


Figure 3. Radiant heating coil is shown embedded in concrete floor panel over reinforcing supported by steel beam or joist.

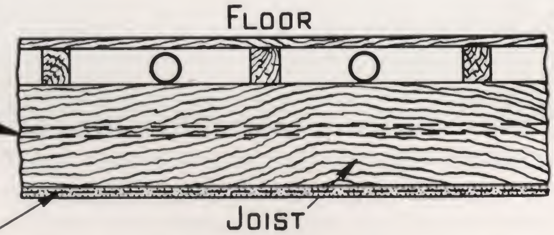


Figure 4. The coil is laid on top of joists with wood flooring supported by sleepers, laid over coil. It is necessary in this case to use some type of insulating board between the joists as shown. This board is supported by stops nailed to the joists.

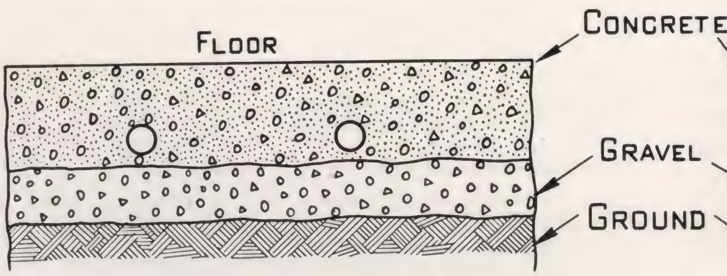


Figure 5. Radiant heating coil is shown embedded in concrete which has been poured on a bed of packed gravel.

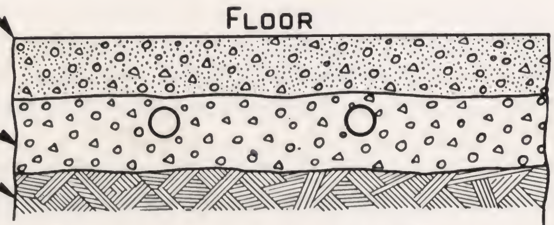


Figure 6. Coil is shown in packed gravel over which the concrete floor has been poured.

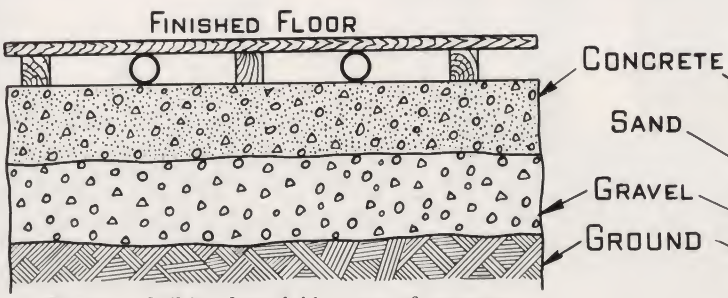


Figure 7. Coil has been laid on top of concrete and wood flooring supported by sleepers laid over the coil.

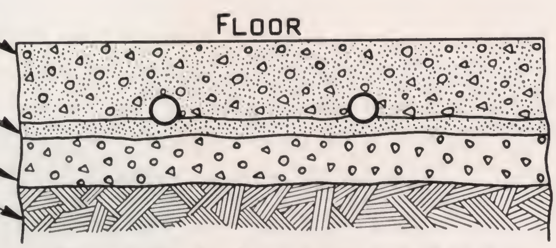
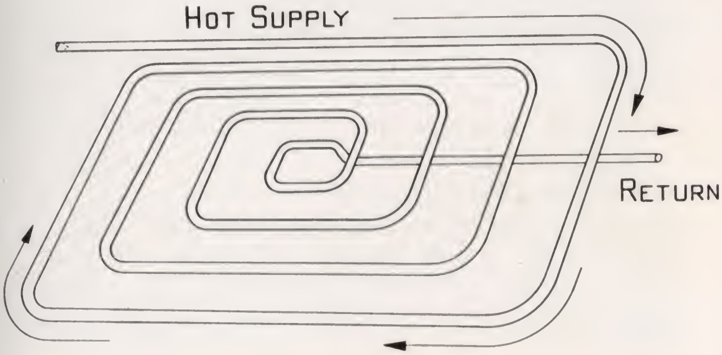
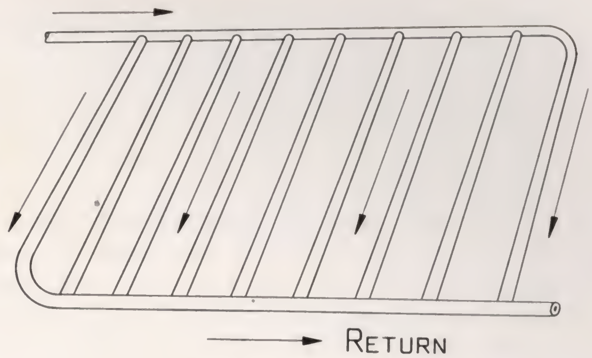


Figure 8. Sand is leveled on a bed of packed gravel, radiant heating coil laid on the sand and the concrete floor poured.

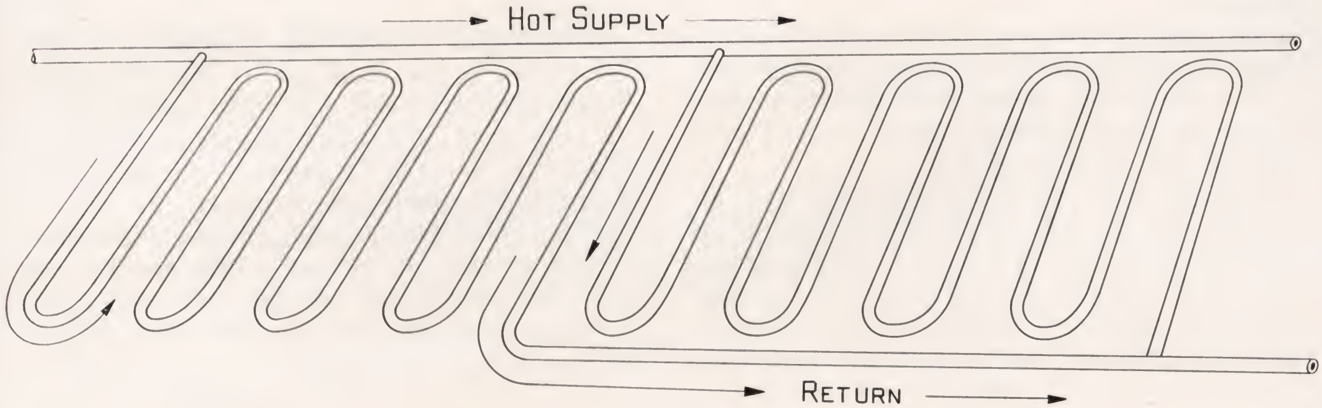
Typical Coil Patterns



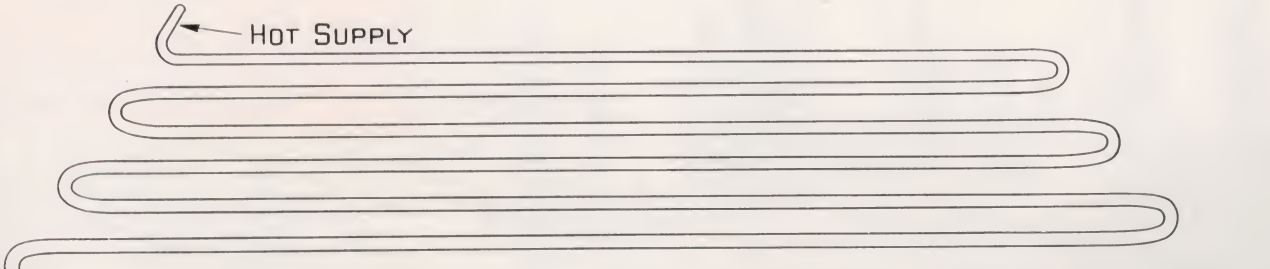
SQUARE COIL
HOT LINES ON ROOM EXTERIOR
COOLER IN CENTER



GRID COIL
MINIMUM BENDING REQUIRED



CONTINUOUS COILS IN PARALLEL.
LOW FRICTION HEAD LOSS



CONTINUOUS COIL
MINIMUM WELDING REQUIRED

U.S.S. NATIONAL Pipe for Radiant Heating

WHETHER FOR USE IN THE HOME, office, or industrial building, pipe for radiant heating systems should be selected on the basis of its inherent characteristics to meet the several requirements for this particular service, and also, on its record of past performance in similar service.

The heating engineer or contractor responsible for the design and installation will rightfully demand pipe that has the necessary physical properties to make smooth, uniform bends and with a minimum of difficulty in the fabricating operation.

He will require also that the pipe used will have good welding quality to assure strong, sound welds, and to save both time and labor in welding the installation.

He will want pipe that offers a minimum of frictional resistance to assure that his design calculations will be translated into actual service performance.

Most important of all, he will want pipe that, on the basis of practical research and the infallible test of time and service, offers a life expectancy, under normal operating conditions, equal to the serviceable life of the building itself.

Obviously, if the pipe selected has been made by a concern with wide experience in the field of domestic and industrial hot water supply piping, and whose resources in materials, manufacturing equipment, and research facilities are without equal, such pipe, produced under these ideal conditions, offers the best assurance that it will meet any requirement for radiant heating service.

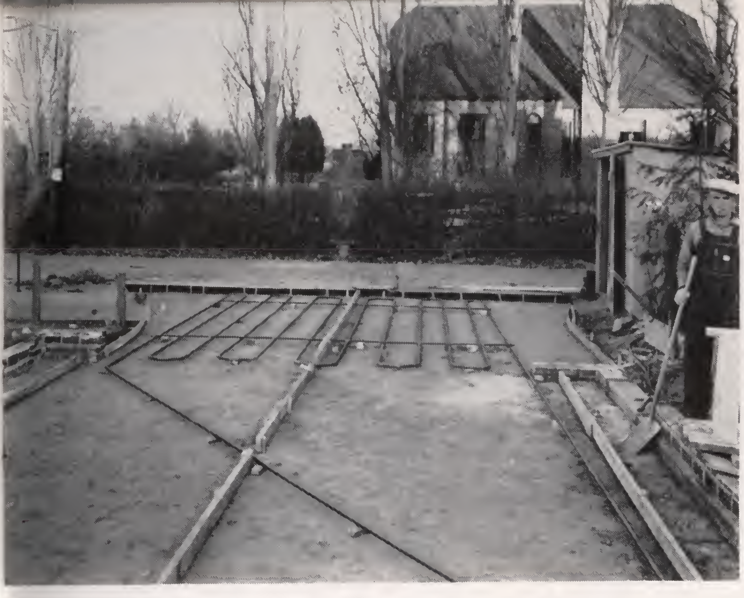
The same NATIONAL advantages that have helped establish steel pipe as the nation's standard for conventional hot water and steam heating systems are all available for radiant heating systems. You can still get the plus value of the Scale Free and Spellerizing Processes, special NATIONAL Pipe features. This means the interior surface of NATIONAL Pipe is smooth, free from mill scale, with minimum frictional resistance. It means also that even though corrosion in radiant heating is an inconsequential factor, as it is in conventional heating systems, these processes, nevertheless, give the pipe maximum corrosion resistance. It means, further, that the weld strength is increased approximately 20 per cent by the extra rolling, which helps give NATIONAL its well-known bending properties.

Still another NATIONAL advantage for radiant heating is that steel pipe is easy to weld—a factor that helps reduce cost on the job and speeds up installation. And, like steel reinforcing bars, it expands at the same rate as concrete and plaster, thus adding strength to the structure.

Whatever measure of value you use to determine the ideal in pipe for radiant heating systems, you will find NATIONAL possesses more practical points or advantages than any other pipe employed for this type of service.

Residence of Elmo Hall, Denver, Colorado. Radiant heating with NATIONAL Steel Pipe installed throughout.

Ceiling coils in same residence.



Garage Driveway of the Elmo Hall residence in Denver.

PHYSICAL PROPERTIES OF U.S.S. NATIONAL STANDARD PIPE FOR RADIANT HEATING

Minimum Yield Strength, 30,000 pounds per square inch.

Minimum Ultimate Strength, 50,000 pounds per square inch.

The center to center spacing required in radiant heating coils is such that excellent bends may be obtained with many portable bending machines available. The table of radii to which pipe may be bent is given as a guide for those sections of a heating system other than in the coils where shorter bends are required.

Radii to which Pipe May Be Bent		
Pipe size	Minimum advisable radius of bends—R	Shortest radius to which pipe can be bent
½	2½	1½
¾	3¾	1¾
1	5	2
1¼	6¼	2¼
1½	7½	2½
2	10	3

All dimensions in inches.
The radius of pipe bends preferably should equal or exceed the dimensions in the column defining minimum advisable radius.

U.S.S. NATIONAL STANDARD PIPE—Black and Galvanized

All weights and dimensions are nominal

Size: nominal	Weight per foot	Pipe		
	Plain end	Thickness	Diameters	
			Outside	Inside
Ins.	Lbs.	Ins.	Ins.	Ins.
⅛	.24	.068	.405	.269
¼	.42	.088	.540	.364
⅜	.57	.091	.675	.493
½	.85	.109	.840	.622
¾	1.13	.113	1.050	.824
1	1.68	.133	1.315	1.049
1¼	2.27	.140	1.660	1.380
1½	2.72	.145	1.900	1.610
2	3.65	.154	2.375	2.067
2½	5.79	.203	2.875	2.469
3	7.58	.216	3.500	3.068
3½	9.11	.226	4.000	3.548
4	10.79	.237	4.500	4.026
5	14.62	.258	5.563	5.047
6	18.97	.280	6.625	6.065

RELATIVE DISCHARGING CAPACITIES OF U.S.S. NATIONAL STANDARD PIPE

Pipe size	Internal diameter D	$D^{5/2}$	Pipe size								
Ins.	Ins.		1/8	1/4	3/8	1/2	3/4	1	1 1/4	1 1/2	2
1/8	.269	.037530	1.0	...	...	...	...	...	...	...	...
1/4	.364	.079938	2.1	1.0	...	...	...	...	...	...	...
3/8	.493	.17065	4.5	2.1	1.0	...	...	...	...	...	...
1/2	.622	.30512	8.1	3.8	1.8	1.0	...	...	...	...	...
3/4	.824	.61634	16	7.7	3.6	2.0	1.0	...	...	...	...
1	1.049	1.1270	30	14	6.6	3.7	1.8	1.0	...	...	...
1 1/4	1.380	2.2372	60	28	13	7.3	3.6	2.0	1.0	...	...
1 1/2	1.610	3.2890	88	41	19	11	5.3	2.9	1.5	1.0	...
2	2.067	6.1426	164	77	36	20	10	5.5	2.7	1.9	1.0
2 1/2	2.469	9.5786	255	120	56	31	16	8.5	4.3	2.9	1.6
3	3.068	16.487	439	206	97	54	27	15	7.4	5.0	2.7
3 1/2	3.548	23.711	632	297	139	78	38	21	11	7.2	3.9
4	4.026	32.523	867	407	191	107	53	29	15	9.9	5.3
5	5.047	57.225	1525	716	335	188	93	51	26	17	9.3
6	6.065	90.589	2414	1133	531	297	147	80	40	28	15
Pipe size	**Internal diameter D**	**$D^{5/2}$**	**Pipe size**								
Ins.	**Ins.**		**2 1/2**	**3**	**3 1/2**	**4**	**5**	**6**	**8**	**10**	**12**
2 1/2	2.469	9.5786	1.0	...	...	...	...	...	...	...	...
3	3.068	16.487	1.7	1.0	...	...	...	...	...	...	...
3 1/2	3.548	23.711	2.5	1.4	1.0	...	...	...	...	...	...
4	4.026	32.523	3.4	2.0	1.4	1.0	...	...	...	...	...
5	5.047	57.225	6.0	3.5	2.4	1.8	1.0	...	...	...	...
6	6.065	90.589	9.5	5.5	3.8	2.8	1.6	1.0	...	...	...

The figure opposite the intersection of any two sizes is the number of smaller size pipes required to equal one of the larger.
Example: How many 1-inch pipes will it take to equal the discharge of one 1¼-inch pipe?
Solution: The figure in the table opposite the intersection of these two sizes gives 2–1-inch pipes.

The Arsenal Junior High School, Pittsburgh, Pa., open-air rooms radiant heated.

U.S.S. NATIONAL STANDARD PIPE—INTERNAL PROPERTIES

Size	Diameters		Thickness inches	Circumference inches	Surface/Lineal foot	
	Outside inches	Inside inches			Square inches	Square feet
⅛	.405	.269	.068	.8451	10.141	.0704
¼	.540	.364	.088	1.1453	13.722	.0953
⅜	.675	.493	.091	1.5488	18.586	.1291
½	.840	.622	.109	1.9541	23.449	.1628
¾	1.050	.824	.113	2.5887	31.064	.2157
1	1.315	1.049	.133	3.2955	39.546	.2746
1¼	1.660	1.380	.140	4.3354	52.025	.3613
1½	1.900	1.610	.145	5.0580	60.696	.4215
2	2.375	2.067	.154	6.4937	77.924	.5411
2½	2.875	2.469	.203	7.7566	93.079	.6464
3	3.500	3.068	.216	9.6384	115.66	.8032
3½	4.000	3.548	.226	11.146	133.76	.9289
4	4.500	4.026	.237	12.648	151.78	1.0540
5	5.563	5.047	.258	15.854	190.25	1.3212
6	6.625	6.065	.280	19.054	228.65	1.5878

Size	Lineal feet of tube per square foot of surface	Transverse area square inches	Capacity per Lineal Foot			Length of tube containing one cubic foot
			Cubic inches	Cubic feet, also area in square feet	United States gallons	
⅛	14.200	.0568	.6820	.0004	.0030	2533.8
¼	10.494	.1041	1.2487	.0007	.0054	1383.8
⅜	7.7479	.1909	2.2907	.0013	.0099	754.36
½	6.1410	.3039	3.6463	.0021	.0158	473.91
¾	4.6356	.5333	6.3992	.0037	.0277	270.03
1	3.6413	.8643	10.371	.0060	.0449	166.62
1¼	2.7679	1.4957	17.949	.0104	.0777	96.275
1½	2.3725	2.0358	24.430	.0141	.1058	70.733
2	1.8480	3.3556	40.267	.0233	.1743	42.913
2½	1.5471	4.7878	57.453	.0332	.2487	30.077
3	1.2450	7.3927	88.712	.0513	.3840	19.479
3½	1.0766	9.8868	118.64	.0687	.5136	14.565
4	.9488	12.730	152.76	.0884	.6613	11.312
5	.7569	20.002	240.02	.1389	1.0391	7.1993
6	.6298	28.890	346.68	.2006	1.5008	4.9844

Installation of floor panel for plant of Perfection Pipe Nipple Company, Madison, Ohio. Coils are shown preparatory to laying concrete.

U.S.S. NATIONAL STANDARD PIPE—EXTERNAL PROPERTIES

External diameter	Circumference	Surface per lineal foot		Lineal feet of tube per square foot of surface	Transverse area	Volume or displacement per lineal foot		
Ins.	Ins.	Sq. ins.	Sq. ft.		Sq. ins.	Cubic inches	Cubic feet, also area in square feet	United States gallons
.405	1.2723	15.268	.1060	9.4314	.1288	1.5449	.0009	.0067
.540	1.6965	20.358	.1414	7.0736	.2290	2.7483	.0016	.0119
.675	2.1206	25.447	.1767	5.6588	.3578	4.2942	.0025	.0186
.840	2.6389	31.667	.2199	4.5473	.5542	6.6501	.0038	.0288
1.050	3.2987	39.584	.2749	3.6378	.8659	10.391	.0060	.0450
1.315	4.1312	49.574	.3443	2.9047	1.3581	16.298	.0094	.0706
1.660	5.2150	62.581	.4346	2.3010	2.1642	25.971	.0150	.1124
1.900	5.9690	71.628	.4974	2.0104	2.8353	34.023	.0197	.1473
2.375	7.4613	89.535	.6218	1.6083	4.4301	53.162	.0308	.2301
2.875	9.0321	108.38	.7527	1.3286	6.4918	77.902	.0451	.3372
3.500	10.996	131.95	.9163	1.0913	9.6211	115.45	.0668	.4998
4.000	12.566	150.80	1.0472	.9549	12.566	150.80	.0873	.6528
4.500	14.137	169.65	1.1781	.8488	15.904	190.85	.1104	.8262
5.563	17.475	209.70	1.4563	.6867	24.301	291.62	.1688	1.2624
6.625	20.813	249.76	1.7344	.5706	34.472	413.66	.2394	1.7907

Turkeys are receiving the comfortable benefits of radiant heating. A flock of turkeys at the Kroeger Turkey Farm, Lima, Ohio, thriving on the radiant rays from NATIONAL Steel Pipe coils.

Battery of hover trays at Kroeger Turkey Farm. Trays are heated by hot water by means of ½-inch NATIONAL Steel Pipe coils. The floor panels are 1¼-inch NATIONAL Steel Pipe embedded in concrete.

Section of radiant heated chick room—Lakeview Poultry Farm and Hatchery, Thiel Brothers, Barker, New York.

CALCULATING TRANSMITTED HEAT COEFFICIENTS*

VALUES OF HEAT CONDUCTIVITY (k) AND OF CONDUCTANCE (C)† OF COMMON BUILDING MATERIALS, OF AIR SPACES (a), OF SURFACES (f), AND OF HEAT INSULATION (k).

Units are B.T.U. per hour per degree temperature difference per square foot area and for 1 in. thickness except when otherwise noted.

Material	Thickness, inches	k
Common Building Materials		
Blocks		
Cinder	8	0.62
	12	0.51
Concrete	8	1.00
	12	0.80
Bricks		
Common (clay)	1	5.0
Face (clay)	1	9.2
Glass	—	—
Cement mortar	1	12.0
Concrete	1	12.0
Gypsum fiber	1	1.66
Plaster (gypsum)	1	3.3
Plasterboard	3/8	3.73
	1/2	2.82
Plaster and wood lath	A	2.0
Roofing materials		
Built-up roofing	3/8	3.53
Composition roofing	A	6.5
Shingles		
Asbestos	A	6.0
Slate	1	10.37
Wood	A	1.28
Stone	1	12.0
Stucco	1	12.0
Tile or terrazzo	1	12.0
Tile, hollow clay	4	1.0
	6	0.64
	8	0.60
	12	0.40
	16	0.31
Tile, hollow gypsum	4	0.46
Wood lumber		
Maple	1	1.15
Yellow pine	1	0.80
Yellow pine lap siding	A	1.28
Surfaces and Air Spaces		f
Air spaces	(over 1½ in.)	1.1
Inside surfaces (f_i)		1.6
Outside surfaces (f_o)	at 15 m.p.h.	6.0

Material	Density, lb. per cu. ft.	k‡
Heat Insulating Materials		
Asbestos wood	123	2.70
Balsa wood	20.0	0.58
Balsa wood	7.3	0.33
Balsam wool	2.2	0.27
Cabot's quilt	4	0.255
Celotex	13.2	0.34
Corkboard (pure)	14.0	0.34
	10.6	0.30
Dry zero	1.0	0.24
Eagle insulating wool	9.4	0.27
Fibrofelt	13.6	0.32
Glass wool	1.5	0.27
	0.85	0.25
Hairinsul (loose, 75% hair, 25% jute)	6.3	0.27
Hairinsul (loose, 50% hair, 50% jute)	6.1	0.26
Hairfelt	13.0	0.26
	11.0	0.26
Insulex or Pyrocell	30.0	1.0
	12.0	0.44
Insulite	16.9	0.34
Keystone hair	11.0	0.25
Linofelt	4.9	0.28
Lith	14.3	0.40
Maftex	16.1	0.34
Magnesia (rigid), 85% magnesia, 15% asbestos	19.3	0.51
Masonite	19.8	0.33
Regranulated cork	8.1	0.31
Rock cork	14.5	0.33
Rock wool	10.0	0.27
Rock wool	21.0	0.30
Sawdust	—	1.04
Shavings	—	0.71
Temlok	15.0	0.33
Thermax	24.2	0.46
Thermofelt (felted, jute and asbestos fibers)	10.0	0.37
Thermofelt (felted, hair and asbestos fibers)	7.8	0.28
Thermofill (flaked gypsum)	34.0	0.23
	19.8	0.35
Torfoleum	10.2	0.29

*Courtesy of Publisher, "Heating and Ventilating Reference Data."

"A" appearing in the column headed "Thickness, Inches" means "thickness as applied," not 1 in. thickness.

†Conductance (C) differs from conductivity (k) in that instead of being for 1 in. thickness it is for some other thickness. In column headed "Thickness, Inches" if the thickness shown is 1 in. the corresponding value in next column is "k"; if some thickness other than 1 in. is shown the corresponding value in the "k" column is really (C) and not (k) because the value is for the thickness specified and not for 1 in. thickness.

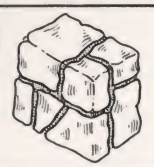
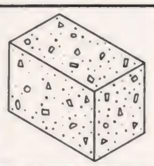
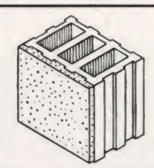
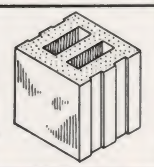
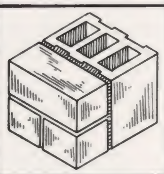
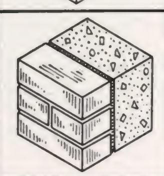
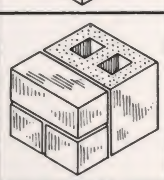
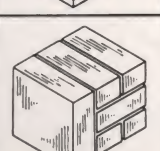
‡Values are for thickness of 1 in., reported by various laboratories but principally from tests at the Bureau of Standards. Tests at mean temperature of 90° mainly, but at 75° in a few cases.

The table shown on this page lists the values of heat conductivity or conductance of common building materials, building surfaces, and materials used for heat insulation. These values when correctly used can be made to furnish a reasonably reliable indication of the amount of heat transmitted through practically any type of building construction. They have been gathered from a variety of sources and it is believed that they represent the consensus of current opinion. Not all types of materials whose resistance to heat flow has been measured are included in this list, some of the less common being omitted to keep table to a usable size.

The values listed should not be confused with those of the coefficient *U* which is the overall heat conductance of a unit section of any wall. They are not values of *U*, but are values often used in calculating *U*.

MASONRY WALLS

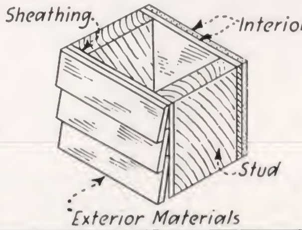
Figures are in B t u per hour per square foot per degree temperature difference, air to air, still air inside, 15 m.p h wind outside

CONSTRUCTION NO.	←EXTERIOR MATERIALS	INTERIOR MATERIALS→	THICKNESS, INCHES	A Plain Wall, no Plaster	B ½" Plaster direct on Walls, no Furring	C (FURRING STRIPS USED) ½" Plaster on Wood Lath or on Metal Lath or on ½" Plaster board	D (FURRING STRIPS USED) ½" Painted Plaster-board, no Plaster	E (FURRING STRIPS USED) ½" Plaster on ½" Rigid Insulation	F (FURRING STRIPS USED) ½" Plaster on 1" Rigid Insulation	G (FURRING STRIPS USED) ½" Plaster on 2" Furring 1⅝" Rock Wool Fill	H (FURRING STRIPS USED) ½" Plaster on 2" Furring ½" Flexible Insulation	I ½" Plaster on 1½" Corkboard set in ½" Cement Mortar
1		Common Brick Throughout	4	0.63	0.57	0.33	0.35	0.24	0.18	0.12	0.21	0.15
2			8	0.44	0.39	0.26	0.26	0.20	0.16	0.11	0.18	0.13
3			12	0.31	0.30	0.22	0.22	0.17	0.14	0.10	0.15	0.12
4			16	0.25	0.24	0.18	0.19	0.15	0.14	0.09	0.14	0.11
5		4" Face Brick, remainder Common Brick	4	0.81	0.72	0.35	0.40	0.26	0.19	0.13	0.22	0.16
6			8	0.49	0.46	0.29	0.30	0.22	0.16	0.12	0.19	0.14
7			12	0.35	0.34	0.24	0.24	0.20	0.15	0.10	0.16	0.12
8			16	0.28	0.26	0.20	0.20	0.16	0.13	0.09	0.15	0.11
9		Limestone or Sandstone	8	0.68	0.62	0.35	0.37	0.25	0.18	0.13	0.21	0.15
10			12	0.56	0.51	0 31	0.33	0 23	0.17	0.12	0.20	0.14
11			16	0.47	0.44	0.28	0.30	0.21	0.16	0.12	0.19	0.14
12			24	0.36	0.34	0.24	0.26	0.19	0.15	0.11	0.17	0.13
13		Concrete	8	0.68	0.62	0.35	0.37	0.25	0.19	0.13	0.21	0.15
14			10	0.62	0.56	0.33	0.35	0.24	0.18	0.12	0.20	0.15
15			16	0.47	0.44	0.28	0.30	0.21	0.16	0.12	0.19	0.14
16			20	0.41	0.38	0.26	0.27	0.20	0.15	0.11	0.17	0.13
17		Hollow Clay Tile With 1" Stucco Exterior Finish	4	0.53	0.49	0.30	0.32	0.23	0.17	0.12	0.19	0.14
18			8	0.39	0.37	0.25	0.26	0.20	0.15	0.11	0.17	0.13
19			10	0.35	0.33	0.23	0.24	0.18	0.14	0.11	0.16	0.12
20			12	0.31	0.29	0.21	0.22	0.17	0.13	0.10	0.15	0.12
21			16	0.24	0.23	0 18	0.19	0.15	0.12	0.09	0.14	0.11
22		Hollow Gypsum Tile, 1" Stucco Ext. Fin.	4	0.33	0.31	0.22	0.23	0.18	0.14	0.10	0.16	0.12
23		Cinder Blocks With one Air Cell Across Heat Flow	8	0.42	0.39	0.26	0.27	0.20	0.16	0.11	0.18	0.13
24			12	0.36	0.34	0.24	0.25	0.19	0.15	0.11	0.17	0.13
25		Cement Blocks With one Air Cell Across Heat Flow	8	0.56	0.52	0.31	0.33	0.23	0.17	0.12	0.20	0.14
26			12	0.49	0.46	0.29	0.30	0.22	0.16	0.12	0.19	0.14
27		4" Brick or 4" Cut Stone with Hollow Clay Tile Backing of This Thickness	6	0.37	0.35	0.24	0.25	0.19	0.16	0.11	0.17	0.13
28			8	0.36	0.34	0.24	0.25	0.19	0.15	0.11	0.17	0.13
29			10	0.32	0.31	0.22	0.23	0.18	0.14	0.10	0.16	0.12
30			12	0.28	0.26	0.20	0.20	0.16	0.13	0.10	0.15	0.11
31		4" Brick or 4" Cut Stone with Concrete Backing of This Thickness	6	0.61	0.56	0.33	0.35	0.24	0.18	0.13	0.20	0.15
32			10	0.51	0.47	0.30	0.31	0.22	0.17	0.12	0.19	0.14
33			16	0.41	0.38	0.26	0.27	0.20	0.15	0.11	0.17	0.13
34		4" Brick Veneer — With Cinder Block Back'g of This Thickness	8	0.35	0.33	0.24	0.24	0.19	0.14	0.11	0.16	0.12
35			12	0.31	0.30	0.22	0.22	0.17	0.14	0.10	0.16	0.12
36		4" Brick Veneer — With Cement Block Back'g of This Thickness	8	0.45	0.42	0.27	0.29	0.21	0.16	0.12	0.18	0.13
37			12	0.40	0.38	0.26	0.27	0.20	0.15	0.11	0.17	0.13
38		4" Cut Stone With Common Brick Backing of This Thickness	8	0.37	0.35	0.24	0 25	0.19	0.15	0.11	0.17	0.13
39			12	0.28	0.27	0.20	0.21	0.16	0.13	0.10	0.15	0.12
40			16	0.23	0.22	0.17	0.18	0.15	0.12	0.09	0.13	0.11

*Courtesy of Publisher, "Heating and Ventilating Reference Data."

WOOD FRAME WALLS

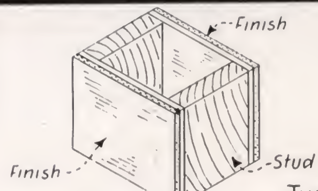
Figures are in B.t.u. per hour per square foot per degree temperature difference, air to air, still air inside, 15 m.p.h. wind outside



Construction No.	Exterior Material ↓	Type Sheathing ↓ / Interior Materials →	A	B	C	D	E	F	G	H
			Plain Wall - no Plaster ½" Plaster Board on Studding.	½" Plaster on Wood Lath on Metal Lath, or on ½" Plaster Board.	½" Plaster on ½" Rigid Insulation on Studding	½" Plaster on 1" Rigid Insulation on Studding	½" Plaster on 1½" Corkboard on Studding	Same as B, but with Stud faced one side with bright Aluminum Foil	Same as B plus ½" Flexible Insulation against Sheathing	Same as B plus 3⅝" Rock Wool between Studding
41	Wood Siding or Clapboard	Wood Sheathing - 1"	0.25	0.24	0.19	0.15	0.11	0.19	0.17	0.060
42		Rigid Insulator Sheathing - ½"	0.23	0.22	0.18	0.14	0.11	0.18	0.16	0.059
43		Plaster board Sheathing - ½"	0.28	0.27	0.20	0.16	0.12	0.21	0.18	0.062
44	Wood Shingles	Wood Sheathing - 1"	0.24	0.23	0.18	0.14	0.11	0.18	0.16	0.059
45		Rigid Insulator Sheathing ½"	0.19	0.19	0.15	0.12	0.10	0.15	0.14	0.056
46		Plaster board Sheathing - ½"	0.24	0.24	0.19	0.15	0.11	0.19	0.16	0.060
47	Stucco	Wood Sheathing - 1"	0.31	0.29	0.22	0.16	0.12	0.22	0.19	0.063
48		Rigid Insulator Sheathing - ½"	0.27	0.26	0.20	0.16	0.12	0.20	0.18	0.062
49		Plasterboard Sheathing - ½"	0.40	0.38	0.26	0.19	0.14	0.27	0.22	0.066
50	Brick Veneer	Wood Sheathing - 1"	0.23	0.23	0.18	0.14	0.11	0.18	0.16	0.059
51		Rigid Insulator Sheathing - ½"	0.23	0.22	0.18	0.14	0.11	0.18	0.16	0.059
52		Plasterboard Sheathing - ½"	0.31	0.30	0.22	0.17	0.12	0.22	0.19	0.063

WOOD FRAME PARTITIONS

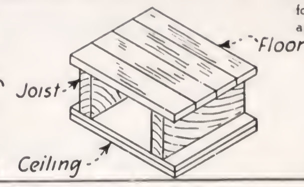
Figures are in B.t.u. per hour per square foot per degree temperature difference air to air still air both sides



Construction No.	Finish ↓ / Type of Partitions →	A	B	C	D	E	F
			Double Partitions				
		Single Partitions (one Side open)	Air Spaces Between Studding	Gypsum Fill Between Studding	One side of Stud Space Faced with bright Alum. Foil	½" Flexible Insulation Between Studding (in Air Space)	3⅝" Rock Wool Fill Between Studding
53	Plaster on Wood lath or ⅜" Plasterboard	0.60	0.33	0.11	0.24	0.21	0.063
54	Plaster on Metal Lath	0.68	0.38	0.11	0.27	0.22	0.065

WOOD FRAME FLOORS & CEILINGS

Figures are in B.t.u. per hour per square foot per degree temperature difference, air to air still air both sides

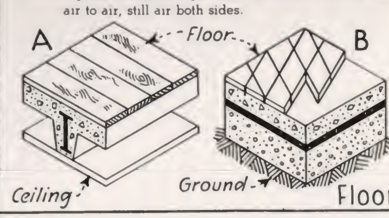


Construction No.	Ceiling Material ↓	Insulation Between Joists ↓ / Type of Flooring →	A	B	C	D	E
			No Flooring	Flooring (Y. P.) on Joists	Flooring (Y. P.) on ½" Rigid Insulation on Joists	H. W. Flooring on Y. P. Sub-Flooring on Joists	¼" Battleship Linoleum on Y. P. Flooring
55	No Ceiling	No Insulation	—	0.45	0.27	0.34	0.34
56	Plaster on Wood Lath or ⅜" Plasterboard	No Insulation	0.60	0.28	0.20	0.24	0.24
57	Plaster on ½" Rigid Insulator	No Insulation	0.34	0.21	0.16	0.18	0.18
58	Metal Lath Plaster	½" Rigid or Flexible	0.25	0.17	0.14	0.15	0.15
59	Metal Lath Plaster	Bright Aluminum Foil	0.29	0.22	0.17	0.19	0.19
60	Metal Lath Plaster	3⅝" Rock Wool	0.066	0.062	0.056	0.059	0.059
61	1½" Corkboard & Plaster	No Insulation	0.16	0.12	0.10	0.11	0.11

*Courtesy of Publisher, "Heating and Ventilating Reference Data."

CONCRETE FLOORS & CEILINGS

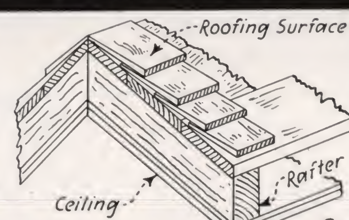
Figures are in B.t.u. per hour per square foot per degree temperature difference, air to air, still air both sides.



Construction No.	Construction Type	Floor Construction	Material under Floor	Thickness of Concrete	A Bare Concrete Floor	B Y.P. Flooring on Wood Sleepers Embedded in Concrete	C H.W. Flooring on Y.P. Sub-Flooring on Wood Sleepers Embedded in Concrete	D 1" Tile or Terrazzo on Concrete	E ¼" Battleship Linoleum on Concrete
62	A	Floor Slab Exposed. No Finished Ceiling Beneath.		4	0.63	0.39	0.30	0.60	0.43
63				6	0.57	0.37	0.28	0.55	0.40
64				8	0.52	0.35	0.27	0.50	0.38
65				10	0.48	0.33	0.26	0.46	0.35
66	A	½" Plaster. Direct on Under Surface of Concrete		4	0.58	0.37	0.28	0.55	0.40
67				6	0.52	0.35	0.27	0.50	0.38
68				8	0.48	0.33	0.26	0.47	0.36
69				10	0.45	0.31	0.25	0.43	0.34
70	A	¾" Plaster on Wood or Metal Lath. (Suspended or Furred Ceiling)		4	0.37	0.27	0.22	0.36	0.29
71				6	0.35	0.26	0.21	0.34	0.28
72				8	0.33	0.25	0.21	0.32	0.26
73				10	0.31	0.24	0.20	0.30	0.25
74	A	½" Plaster on ½" Rigid Insulation (Suspended or Furred Ceiling)		4	0.24	0.20	0.17	0.24	0.21
75				6	0.23	0.19	0.16	0.23	0.20
76				8	0.22	0.18	0.16	0.22	0.19
77				10	0.22	0.18	0.16	0.21	0.19
78	A	½" Plaster on 1½" Corkboard in 1½" Cement Mortar on Concrete		4	0.15	0.13	0.12	0.15	0.13
79				6	0.14	0.13	0.11	0.14	0.13
80				8	0.14	0.12	0.11	0.14	0.13
81				10	0.14	0.12	0.11	0.14	0.12
82	B	Stone Concrete Directly on Ground, no Insulation, no Cinder Concrete.		4	1.05	0.52	0.37	0.96	0.59
83				6	0.89	0.48	0.34	0.83	0.54
84				8	0.78	0.44	0.32	0.73	0.49
85				10	0.69	0.41	0.31	0.65	0.46
86	B	3" Cinder Concrete on Ground, Insulation on top of this, under Stone Concrete.	No Insulation	4	0.64	0.40	0.30	0.61	0.44
87			No Insulation	8	0.53	0.35	0.27	0.51	0.38
88			1" Rigid Insulat.	4 or 8	0.21	0.18	0.15	0.21	0.18
89			2" Corkboard	4 or 8	0.12	0.11	0.10	0.12	0.11

WOOD FRAME PITCHED ROOFS

Figures are in B.t.u per hour per square foot per degree temperature difference, air to air, still air inside, 15 m.p.h. wind outside.



Construction No.	Roofing Surface	Type Insulation	A No Ceiling	B ½" Plaster on Wood or Metal Lath or ⅜" Plasterboard	C ½" Rigid Insulation With or Without ½" Plaster	D ½" Plaster on 1" Rigid Insulation	E ½" Plaster on 1½" Corkboard	F ½" Plaster on 2" Corkboard
90	Wood Shingles on Wood Strips	No Insulation	0.45	0.28	0.22	0.17	0.12	0.10
91	Asphalt Composition, Tile or Slate on Wood Sheathing	No Insulation	0.54	0.31	0.23	0.17	0.13	0.10
92	Wood Shingles on Wood Strips, or Asphalt Shingles, Composition Roofing, or Slate or Tile Roofing on Wood Sheathing	½" Flexible	0.25	0.16	0.15	0.12	0.098	0.084
93		1" Flexible	0.17	0.12	0.12	0.10	0.083	0.073
94		Aluminum Foil on one side of Air Space	—	0.23	0.18	0.14	0.11	0.092
95		3⅝" Rockwool	—	0.063	0.059	0.054	0.050	0.045

MASONRY PARTITIONS

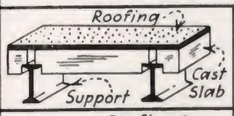
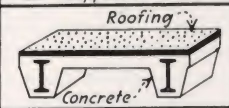
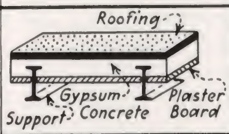
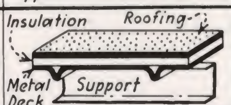
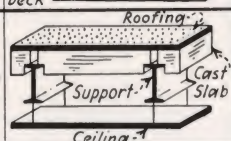
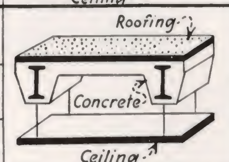
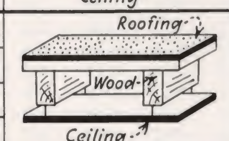
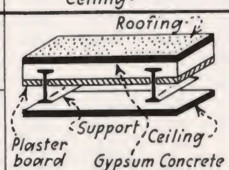
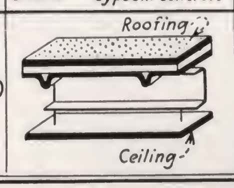
Figures are in B.t.u. per hour per square foot per degree temperature difference, air to air, still air both sides.

No.	Partition	No Plaster	Plastered One Side	Plastered Both Sides
96	4" Hollow Clay Tile	0.43	0.40	0.38
97	4" Common Brick	0.49	0.45	0.43
98	4" Hollow Gypsum Tile	0.29	0.28	0.27

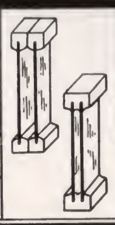
*Courtesy of Publisher, "Heating and Ventilating Reference Data."

FLAT & BUILT-UP ROOFS

Figures for all constructions on this sheet are in B.t.u. per hour per square foot per degree temperature difference, air to air, still air inside, 15 m.p.h. wind outside

Construct. No			Thickness of Roof Deck	A No Insulation	B Rigid Insulation ½"	C Rigid Insulation 1"	D Rigid Insulation 1½"	E Rigid Insulation 2"	F Corkboard 1"	G Corkboard 1½"	H Corkboard 2"
99		Precast	1 5/8	0.83	0.37	0.23	0.17	0.14	0.22	0.16	0.13
100		Concrete	2	0.81	0.36	0.23	0.17	0.14	0.22	0.16	0.13
101			4	0.71	0.34	0.22	0.17	0.14	0.21	0.16	0.12
102			6	0.64	0.32	0.21	0.16	0.13	0.20	0.15	0.12
103		Wood	1	0.50	0.28	0.20	0.15	0.12	0.19	0.14	0.11
104			1½	0.37	0.24	0.17	0.14	0.11	0.17	0.13	0.11
105			2	0.32	0.22	0.16	0.13	0.11	0.16	0.12	0.10
106			4	0.18	0.14	0.12	0.10	0.085	0.11	0.094	0.081
107		2" Gypsum Fiber Concrete on ½" Plasterboard	2½	0.38	0.24	0.18	0.14	0.12	0.17	0.13	0.11
108			3½	0.31	0.21	0.16	0.13	0.11	0.15	0.12	0.10
109		Flat Metal	–	0.94	0.39	0.24	0.18	0.14	0.23	0.16	0.13
110		Precast	1 5/8	0.42	0.26	0.18	0.14	0.12	0.18	0.14	0.11
111		Concrete	2	0.42	0.26	0.18	0.14	0.12	0.18	0.14	0.11
112			4	0.39	0.25	0.18	0.14	0.12	0.17	0.14	0.11
113			6	0.37	0.24	0.17	0.14	0.11	0.17	0.13	0.11
114		Wood	1	0.32	0.21	0.16	0.13	0.11	0.15	0.12	0.10
115			1½	0.26	0.23	0.15	0.12	0.10	0.14	0.11	0.095
116			2	0.24	0.21	0.14	0.11	0.097	0.13	0.11	0.091
117			4	0.15	0.12	0.10	0.088	0.078	0.10	0.085	0.074
118		2" Gypsum Fiber Concrete on ½" Plasterboard	2½	0.27	0.19	0.15	0.12	0.10	0.14	0.11	0.096
119			3½	0.23	0.17	0.13	0.11	0.096	0.13	0.11	0.090
120		Flat Metal	–	0.45	0.27	0.19	0.15	0.12	0.18	0.14	0.11

WINDOWS & SKYLIGHTS

121		Single Sash	Double Strength Window Glass 1/8 in Thick	1.24
122		Double Sash		0.58
123		Triple Sash		0.38
124		Double Glazed Single Sash		0.63
125		Plate Glass 3/8 in Thick		1.19

WOOD & METAL DOORS

126		Thin Wood Doors with Glass	1.24
127		1" Wood Doors	0.70
128		2" Wood Doors	0.45
129		3" Wood Doors	0.30
130		Metal and Asbestos Doors	0.65

*Courtesy of Publisher, "Heating and Ventilating Reference Data."

HEAT LOSSES AND INFILTRATION THROUGH DOORS AND WINDOWS*

The purpose of this sheet is to enable the user rapidly and accurately to determine the heat losses and infiltration through doors and windows by the use of tables for standard size doors and windows, eliminating the laborious calculation of crack lengths. The method and the data were developed by Ralph A. Krauss, combustion engineer, Anthracite Industries Laboratory, and appear here with slight modifications.

Tables III, IV, and VII give the heat losses through standard-size windows and doors, based on a 70° F. temperature difference and 15 mile wind. Table I permits adjustment to other temperature differences, and Table II of other wind velocities.

The first two columns give the width and height of the window or door opening in inches. The opening refers to the outside dimensions of the window or door. The next column gives the area in square feet. This figure is not used in calculating window losses, but is subtracted from the gross wall area to obtain the actual or net area of the wall structure.

The transmission loss is given in Btu per hour for single and double glass, the latter referring to two separate thicknesses of glass with an air space between. The presence of storm sash fulfills this condition, but "double-strength" glass does not. For single glass, the transmission coefficient is 1.13 Btu per sq. ft. per hr. per degree F., and for double glass, 0.45 Btu.

Doors consisting largely of glass or thin wood panels are assumed to have the same transmission loss as windows of the same size. For solid wood doors, multiplying factors are given in Table VI.

Infiltration loss depends upon a number of factors, including the construction of the window and its fit. The tables are calculated on the basis of standard data.

Infiltration losses through types of windows not given in the tables may be calculated by multiplying the loss shown under "Weatherstripped, Poor," by the factors given in Table V.

Metal windows sometimes consist of part stationary and part movable sections. In this case, count the entire window for transmission loss and the movable part for infiltration loss.

The tables have been based upon a 15 mile wind. For other wind velocities, use the multiplying factors in Table II.

Infiltration is assumed to occur only on the windward half of the building, although it is safer to compute the total possible leakage of the entire structure, making sure that the infiltration loss is not less than half of this figure.

After the heat loss and infiltration have been determined for a given room from the tables for a 70° F. temperature, the total can be corrected for other design temperature differences by multiplying by the factors in Table I.

TABLE I.—CORRECTION FACTORS FOR TEMPERATURE DIFFERENCE

Design temperature difference, F.	Multiplying factor
90	1.29
85	1.21
80	1.14
75	1.07
70	1.00
65	0.93
60	0.86
55	0.79
50	0.72
45	0.64
40	0.57
35	0.50
30	0.43

TABLE II.—WIND CORRECTION FACTORS

Wind, M.p.h.	Factor
3	0.1
4	0.15
5	0.2
6	0.3
8	0.45
10	0.60
12	0.75
14	0.90
16	1.10
18	1.25
20	1.40
25	1.80

TABLE III.—HEAT LOSSES, SINGLE CASEMENT WINDOWS

Size of opening (inches)		Area (sq. ft.)	Transmission loss at 70° F. diff. (B.t.u. per hr.)		Infiltration loss at 70° F. diff. 15 mile wind (B.t.u. per hr.)			
					Weather-stripped		Non-weather-stripped	
Width	Height		Single glass	Double glass	Aver.	Poor	Aver.	Poor
20½	21	3.0	237	95	205	296	346	970
20½	45	6.4	506	202	325	468	545	1530
20½	53	7.54	595	238	363	524	610	1710
22½	23	3.75	296	118	224	324	378	1060
24	24	4.0	316	126	248	343	400	1120
24	30	5.0	395	157	268	386	450	1260
24½	25	4.25	335	134	253	365	425	1190
24½	29	4.92	388	155	265	382	445	1250
24½	53	9.0	712	284	381	550	640	1800
25½	23	4.08	322	129	240	346	404	1130
28½	25	4.95	390	156	265	382	445	1250
28½	29	5.74	452	180	284	410	478	1340
28½	31	6.12	473	193	295	425	495	1390
28½	35	6.92	545	218	314	454	528	1480
28½	41	8.10	640	255	343	495	578	1620
28½	47	9.30	735	293	374	540	628	1760
28½	53	10.5	830	331	403	582	678	1900
31½	29	6.35	500	200	300	430	502	1410
31½	33	7.22	570	228	320	460	535	1500
31½	35	7.66	605	242	330	474	552	1550
31½	37	8.10	640	255	340	490	570	1600
31½	41	8.96	709	283	360	518	603	1690
31½	47	10.3	815	325	390	560	652	1830
31½	53	11.6	915	366	420	603	702	1970
34½	29	6.95	548	219	315	453	528	1480
34½	33	7.90	625	249	335	480	560	1570
34½	37	8.85	700	279	355	510	595	1670
34½	41	9.83	788	310	375	540	627	1760
34½	47	11.2	895	352	405	582	678	1900
34½	53	12.6	995	396	435	625	728	2040

*Courtesy of Publisher, "Heating and Ventilating Reference Data."

TABLE IV.—HEAT LOSSES, DOUBLE-HUNG WINDOWS

Window size (inches)		Area (sq. ft.)	Transmission loss at 70° F. diff. (B.t.u. per hr.)		Infiltration loss at 70° F. diff. 15 mile wind (B.t.u. per hr.)			
					Weather-stripped		Non-weather-stripped	
Width	Height		Single glass	Double glass	Aver.	Poor	Aver.	Poor
16	46	5.10	405	162	350	500	580	1620
20	36	5.00	400	160	330	477	545	1545
20	42	5.84	460	184	360	520	595	1685
20	46	6.38	505	202	380	540	625	1740
20	54	7.50	592	236	420	608	694	1970
20	58	8.06	636	255	440	635	725	2060
22	30	4.58	362	145	310	448	512	1450
22	46	7.03	556	221	390	565	650	1810
22	54	8.25	645	260	430	625	720	2020
22	58	8.85	700	280	455	658	750	2130
24	36	6.00	475	189	360	520	600	1680
24	42	7.00	555	222	390	560	645	1810
24	46	7.67	608	242	410	590	680	1920
24	50	8.33	660	262	430	620	715	2000
24	58	9.69	768	315	470	680	780	2180
24	62	10.33	820	326	490	700	810	2290
26	54	9.80	787	308	465	670	775	2170
26	58	10.45	829	329	480	700	800	2260
26	62	11.20	887	352	500	730	840	2350
28	30	5.85	462	185	360	520	595	1485
28	36	7.00	555	222	390	560	645	1810
28	38	7.40	587	233	400	575	660	1860
28	42	8.16	647	258	420	605	700	1950
28	46	8.95	710	283	435	630	725	2040
28	50	9.75	775	307	460	660	760	2160
28	54	10.50	833	331	480	690	800	2250
28	56	10.90	862	344	490	710	810	2300
28	58	11.25	894	354	500	720	830	2340
28	62	12.05	955	380	520	745	860	2420
28	66	12.80	1013	403	540	775	900	2520
30	42	8.75	695	276	430	625	720	2020
30	54	11.25	894	354	490	710	800	2280
30	58	12.05	955	380	510	740	850	2400
30	62	12.90	1020	406	540	780	900	2520
31	30	6.46	510	204	382	554	630	1790
31	36	7.75	612	244	413	596	680	1930
31	42	9.05	715	285	442	640	730	2070
31	46	9.90	782	312	462	670	763	2160
31	50	10.80	850	340	482	700	800	2260
31	54	11.60	915	365	503	725	830	2370
31	58	12.50	990	394	522	755	862	2450
31	62	13.42	1055	423	543	785	895	2540
31	66	14.25	1120	450	563	815	930	2640
32	54	12.00	950	378	510	740	850	2400
32	58	12.90	1020	406	530	770	880	2460
32	62	13.80	1090	435	550	800	920	2580
34	30	7.10	560	224	405	585	670	1895
34	36	8.50	670	268	435	630	720	2040
34	42	9.90	780	312	455	660	750	2130
34	46	10.85	855	342	475	685	785	2230
34	50	11.80	930	372	495	715	820	2320
34	54	12.75	1010	404	520	755	880	2460
34	58	13.70	1080	430	535	775	885	2500
34	62	14.60	1155	460	565	815	940	2640
34	66	15.60	1230	490	575	831	950	2690
36	46	11.50	910	362	500	723	825	2340
36	50	12.50	990	394	520	750	860	2440
36	54	13.50	1065	425	540	780	890	2530
36	56	14.00	1100	440	550	795	908	2580
36	58	14.50	1145	460	560	810	925	2620
36	62	15.50	1220	488	580	840	956	2720
36	66	16.50	1300	520	600	868	990	2810
40	46	12.75	1005	402	530	766	875	2480
40	50	13.90	1095	438	550	795	908	2575
40	54	15.00	1185	472	570	825	940	2670

TABLE V.—WINDOW CORRECTION FACTORS

(Multipliers for Table IV—Weatherstripped, Poor)

Type	Multiplier
Double-hung metal	2
Same, weatherstripped	1
Industrial, pivoted, metal	5
Residential metal casement	1.5

TABLE VI.—DOOR CORRECTION FACTORS

(Multipliers for Table VII—Double Glass)

Actual thickness of door, inches	Multiplying factor
25/32	1.5
1 1/16	1.3
1 5/16	1.2
1 3/8	1.1
1 5/8	1.0
2 1/8	0.85
2 5/8	0.75

TABLE VII.—DOORS AND DOUBLE CASEMENTS

Size of opening (inches)		Area (sq. ft.)	Transmission loss at 70° F. diff. (B.t.u. per hr.)		Infiltration loss at 70° F. diff. 15 mile wind (B.t.u. per hr.)			
					Weather-stripped		Non-weather-stripped	
Width	Height		Single glass	Double glass	Aver.	Poor	Aver.	Poor
SINGLE DOORS								
24	78	13.0	1025	410	1190	2380	2380	4760
24	80	13.3	1050	420	1215	2430	2430	4860
28	78	15.2	1200	480	1240	2480	2480	4960
28	80	15.6	1230	492	1250	2500	2500	5000
30	78	16.2	1280	512	1260	2520	2520	5040
30	80	16.7	1320	530	1285	2570	2570	5140
32	80	17.8	1405	562	1310	2620	2620	5240
34	82	19.3	1525	610	1355	2710	2710	5420
36	80	20.0	1580	632	1355	2710	2710	5420
36	84	21.0	1660	665	1400	2800	2800	5600
DOUBLE OR FRENCH DOORS AND WINDOWS								
32½	35½	7.8	615	246	430	620	715	2010
36½	41½	10.5	830	332	490	710	820	2300
36½	45¾	11.5	910	365	505	730	840	2360
36½	53¾	13.6	1070	428	585	845	975	2740
40½	35½	10.0	790	316	467	675	780	2190
40½	41½	11.7	925	370	515	740	855	2400
40½	45¾	12.8	1010	404	550	790	910	2550
40½	53¾	15.1	1190	475	605	875	1010	2830
44½	53¾	16.7	1320	530	625	900	1040	2920
48	78	26.0	2060	825	1925	3850	3850	7700
48	80	26.7	2110	844	1960	3920	3920	7840
48	84	28.0	2210	884	2025	4050	4050	8100
60	78	32.5	2570	1030	2065	4130	4130	8260
60	80	33.3	2640	1060	2100	4200	4200	8400
60	84	35.0	2770	1110	2165	4330	4330	8660

The above figures are for doors consisting of glass or thin wood panels. For solid wood doors, multiply the transmission-loss figures given for double glass by the factors in Table VI.

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